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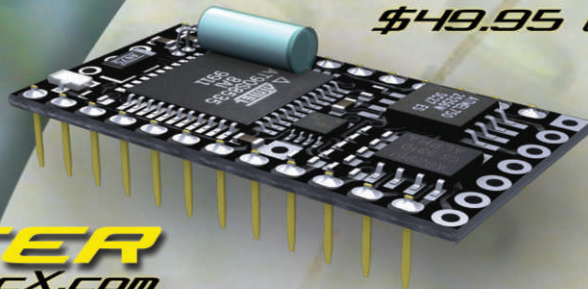
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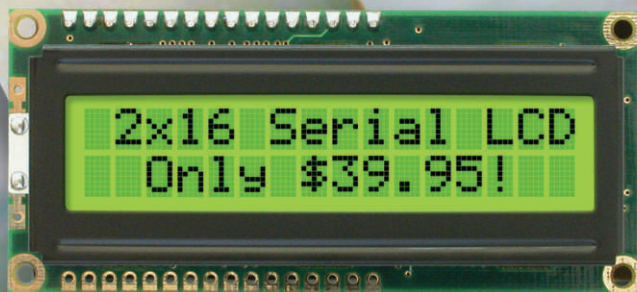
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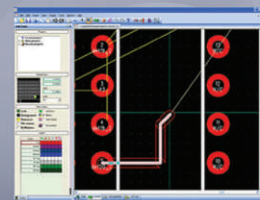
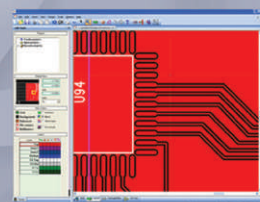
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Photo Courtesy Michael Miller

How MRT Too Tackled Robo-Magellan

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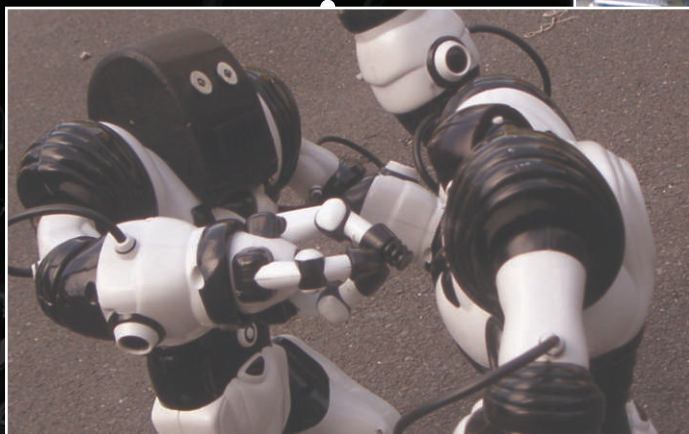
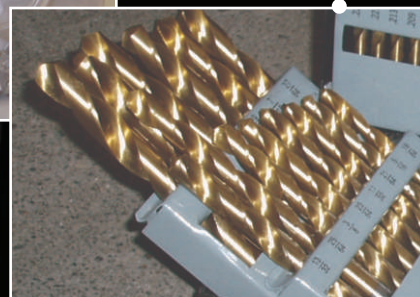
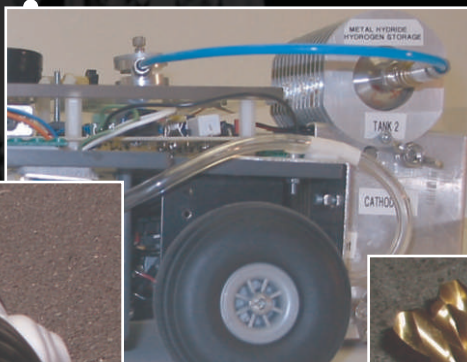
Out With Batteries, In With Fuel Cells!

by Alexander Wilhelm

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FIRST Frenzy, Part 4

by Bryce and Evan Woolley



00 Mind / Iron



by Dan Danknick

It was like a home and garden show for people that create and invent. Instead of fishing lures and RVs, there were active optical sensor packages and high performance DC motors. Software development kits replaced cast iron cooking sets. Caps and jackets read "Raytheon" and "Kawada Industries" instead of "Browning" and "Home Depot." I am, of course, describing the RoboNexus show that was held Oct. 22-23 in Santa Clara, CA. If you ever wondered what it would be like to immerse yourself in robotics, this was the dream come true!

When the show opened to the public on Friday, it took less than an hour for the hallways to start buzzing with questions from the interested — and answers from the interesting. Everything was up for discussion; there were no static displays, manned by grim-faced "suits." No, they were replaced with excited developers that wanted to share their successes — and development failures — with anyone that was interested in listening.

Some might think that little money changed hands (Kawada didn't expect to sell any more \$500,000.00 HRP-2 bipeds, for example), but the value of ideas that moved between people is probably the better success metric. This industry is still emerging from its infancy, but there is a lot of energy driving the ideas.

I noticed that there were a lot of teenage kids at the show. This is good news, since technology and the hope it brings is in direct odds with many of the cultural messages flying around. Will pop music or sports stars arrest global warming, or provide clean water for developing countries? As inventor Dean Kamen is so frequent to point out, the answer is an emphatic "no" — such

advances will instead come from engineers. And engineers arise from inspired students.

If the number of photographers and video crews is any indication, our Tetsujin 2004 event was also inspiring — as well as interesting! A smashing success by anyone's reckoning, six teams of competitors and their wildly different exosuits were a constant draw. We held four lift sessions over the two days, with suspense building to the final, highest

From garage-based engineers with servo controlled Hexapods, to Kawada's life-sized walking android, RoboNexus showed us the future is closer than we thought. Almost all major robot manufacturers were there — as well as robot games competitors with resumes in hand. Everyone was impressed with how, with the possible exception of a tired magazine editor and a jaded columnist, who stayed in the bar most of the last day.
— Dave Calkins, RSA President

weight left of the event: 1140 lb by Pinch Point, the entry of Chuck Pitzer. (Check out our photo collage on pages 34-35 for even more details, and the Appetizer column on page 81 by event winner Alex Sulkowski.)

In the end, the real gist of RoboNexus was that a large number of companies are currently investing in commercial robotics — not because it is simply cool, but because they are getting a handle on the market ideas that will make it viable. Whether it is surveillance, entertainment, care for the elderly, or strength augmentation, robots will pop up more and more in our collective future.

This is a good time to be a roboticist and I hope that your knowledge increases each month by reading *SERVO Magazine*. Who knows, you might be an exhibitor at the 2005 RoboNexus! **SV**

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PUBLISHER

Larry Lemieux

publisher@servomagazine.com

ASSOCIATE PUBLISHER/ VP OF SALES/MARKETING

Robin Lemieux

robin@servomagazine.com

MANAGING/TECHNICAL EDITOR

Dan Danknick

dan@servomagazine.com

ASSOCIATE EDITOR/ PRODUCTION MANAGER

Alexandra Lindstrom

alexa@servomagazine.com

CIRCULATION DIRECTOR

Mary Descaro

subscribe@servomagazine.com

WEB CONTENT/STORE

Michael Kaudze

michael@servomagazine.com

PRODUCTION/GRAPHICS

Shannon Lemieux

STAFF

Kristin Rutz

Dawn Saladino

INTERN

Mandy Garcia

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BIO → FEEDBACK

Dear *SERVO*,

I enjoy reading your magazine and *Nuts & Volts* and the previous issue of *SERVO* got me interested in BEAM robots. I built the photovore and anxiously waited for the next issue. When I got it, I built the nv neuron, flipped the switch, and it didn't work correctly. It stayed on only when IN was connected to Vcc. I practically pulled my hair out examining and rebuilding it. So, I checked the Internet and quickly found that the capacitor in the neuron WASN'T POLARIZED, so I substituted a nonpolar one and it worked perfectly as described in the article. I'm not mad, just glad it works, but I would like to know what caused that error. It's still a cool circuit, though.

D. McGrath
via Internet

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A Big *SERVO* Thanks!

All of the staff here at *SERVO* Magazine would like to thank Ted Shimoda for his tireless work on the construction of the Tetsujin 2004 stage. For those of you who missed the event at RoboNexus, this steel structure was responsible for supporting the exosuits — and potentially handling a cataclysmic drop of 1,400 lbs of iron weight plates! The stage weighed over two tons and Ted volunteered his time to come down and fabricate it with Editor Dan. Ted is a top-notch robot builder, so be sure to visit his website at www.teamthinktank.com

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AN RF COMMAND LINK FOR YOUR ROBOSAPIEN

Enhance Your IR Remote

by **Olivier Lanvin**

The goal of this hack is to change the transmission mode of the remote control of RS (RoboSapien) to use RF (radio frequency) instead of infrared (IR). Why?

First, I wanted to be able to use two RSs in the same place. The stock remote control does not use any specific coding, so two RSs will respond simultaneously to a press on any remote, making a "ninja fight" or any other dual game almost impossible.

However, someone proposed to use a cut paper roll to "hide" the front source of IR, enabling some independent control from behind, but — regardless of its simplicity — this solution is not very effective

because of the high sensitivity of the IR photocell receiver of the RS, which makes the robot react to indirect IR beam reflections off the walls and the ceiling.

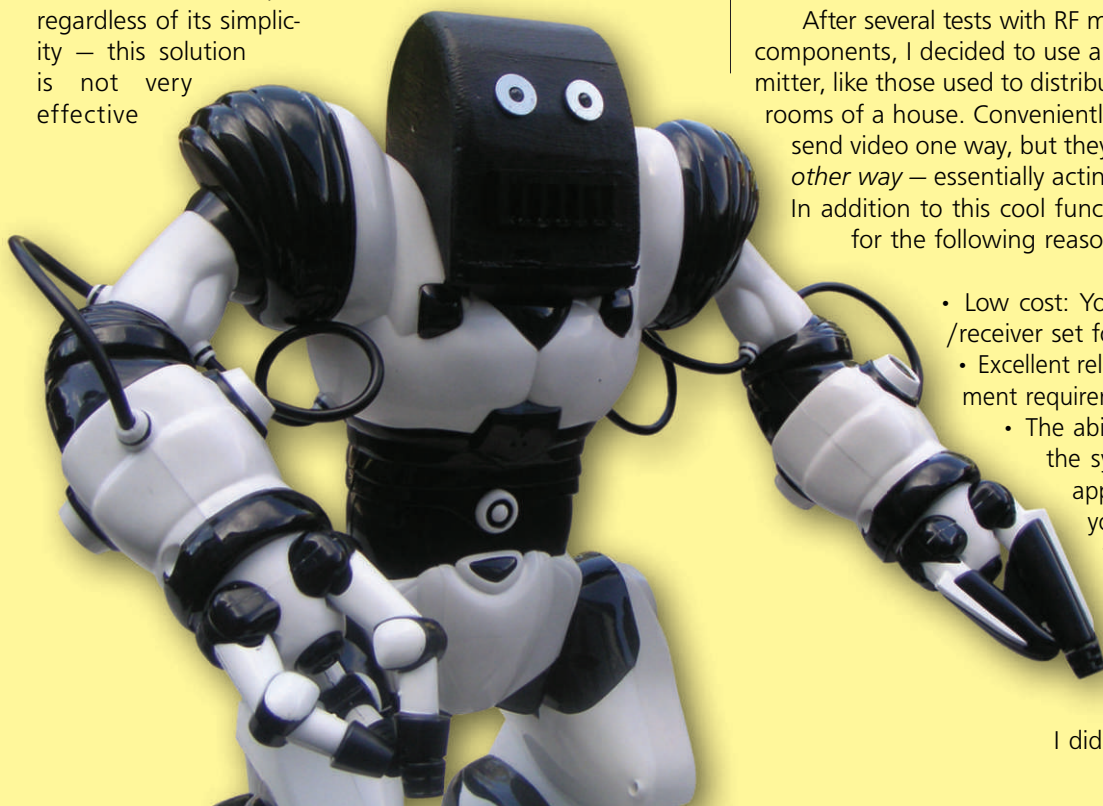
With my hack, any interference between the two remotes is eliminated. As a bonus, you can command your RS from another room — at a distance of around 50 meters (you could even equip him with a mini-video camera and pilot him from elsewhere via a control screen).

This hack does not require opening the RS or the remote. It consists of two "add-ons" that fit on the head of the RS on one side and on the front of the IR remote controller.

After several tests with RF modules and discrete electronic components, I decided to use a commercial type video transmitter, like those used to distribute a video source in different rooms of a house. Conveniently, these transmitters not only send video one way, but they send IR commands back *the other way* — essentially acting like an IR remote extender! In addition to this cool functionality, I chose this scheme for the following reasons:

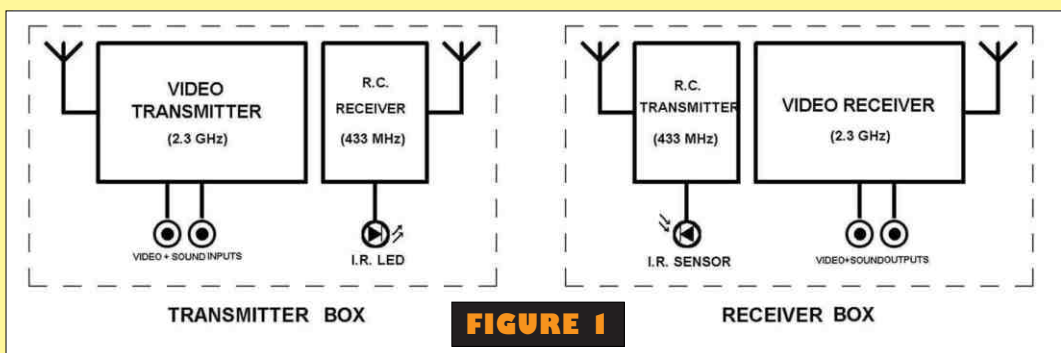
- Low cost: You can purchase a transmitter/receiver set for less than \$30.00.
- Excellent reliability, no sophisticated equipment requirements, and no tuning at all.
- The ability to reuse the video part of the system that is not used in this application. As mentioned earlier, you can use the video transmitter/receiver in other projects, including adding video capabilities for your RS.

An example of this is a detail of the modification I did on a commercial unit. There



can be some differences from one model to another, but the general explanations are still valuable, as the functional principles are the same.

Here is the principle scheme of a video transmitter/receiver. As you can see in Figure 1, there are two different parts:



- A video-transmitter/receiver sub-system, which works on the 2.4 GHz band. It carries the video signal and sound from the source to another TV set.
- An infrared remote control relay sub-system – which works in the opposite direction – and uses the 433 MHz band: In the video receiver box, an IR detector receives the signal from the original remote, converts it into an RF signal that is received in the video transmitter box, then re-converts it into an IR signal sent to the device to command. That is the part we are interested in.

Let's go into the practical side. Figure 2 is an external look at a video transmitter (the receiver looks identical).

BEWARE: Before doing irreversible modifications on the device, be sure it works properly for the job; in fact, some models don't work due to the particular coding system of the RS remote control, which is quite different from the way most audio/video remotes work.

To test it, you only need to put the transmitter box (for those with the IR LED) in front of the RS and press any button on the remote in front of the receiver box, but do this in another room, not in sight of the RS. If the RS does not execute your orders, you need to try another model. Figures 3 and 4 show the printed circuit boards of the two devices.

On the left is the transmitter circuit board: You can distinguish the video transmission part with CINCH sockets and a metal shielded module; do this with the 433 MHz receiver using a printed coil that has an IR emitting LED.

On the right is the receiver circuit board with the video receiving circuit, which shows a metal box, too, and the 433 MHz emitting circuit, again with a printed coil and an IR detector between the two little red LEDs.

The next operation is one which requires attention and (a little)



skill: You have to physically separate the two parts of each circuit. For this, you must observe where the power and ground traces are located. This is generally not difficult because the sub-systems are well isolated. Here, we have a CMS 5 V regulator chip (three pins) on each board, which converts the 9 V power to a 5 V regulated voltage for the 455 MHz circuits.

You must cut the circuit board just before this chip in order to keep it on the final module, which you will connect to a 9 V battery. To identify this regulator – if it exists – you can use a simple voltmeter. You must have 9 V on the input and 5 V on the output (middle pin is ground). If there isn't, the regulated power line is common for the whole circuitry, so you could have to wire a new one (a low power one is sufficient) on the module once it is cut off. Each case may be different, but – if you connect a regulated voltage source of

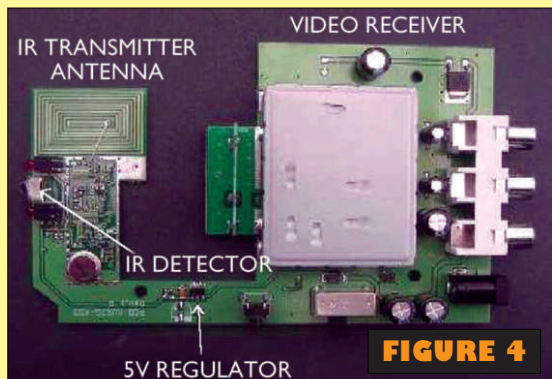
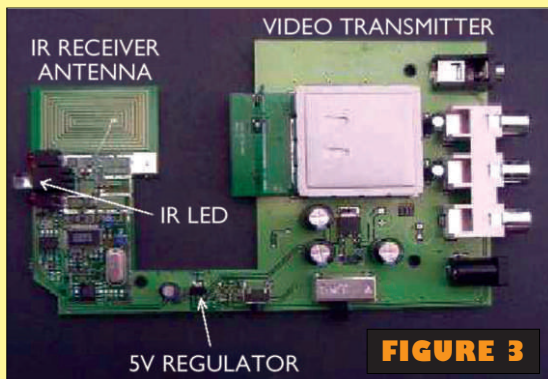
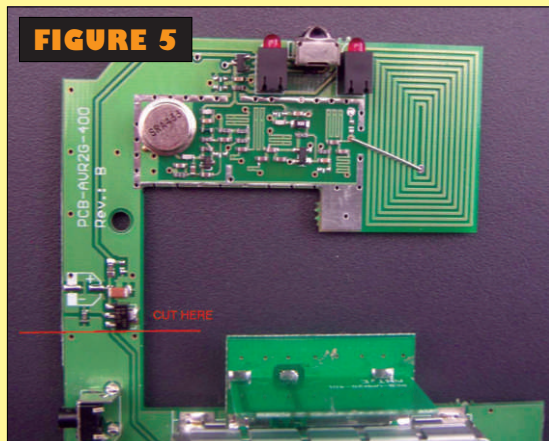
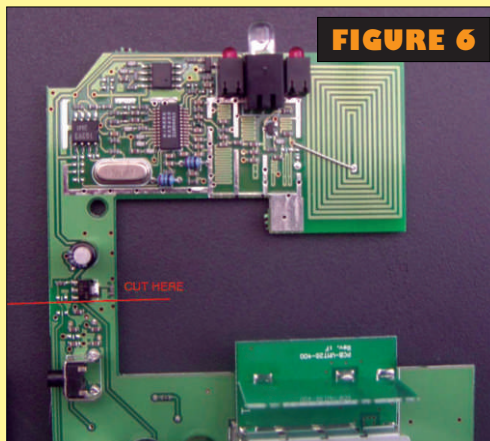


FIGURE 5**FIGURE 6**

the same value as it was in the original circuit — no doubt, it will function properly.

The red line in Figures 5 and 6 shows where to cut the board on the model I hacked. Figure 7 shows the two modules you obtain after this operation. The RF to IR converter is small enough to fit just behind the head of the RS (see Figure 8) and the IR to RF converter can easily fit with its battery cell in a box fixed at the emitting end of the remote.

It is time now for a new test. Connect the + and - wires to the ground and input of the regulator, switch the power on, and try to send an order from another room to the RS. If

it works, that's it! The hard work is done and the rest is a job of mechanical assembly and a bit of painting.

The RS must have his head covered with a light-proof "helmet" so that external IR signals cannot penetrate to the sensor and, symmetrically, the remote's end has to be covered by a "cache" that contains the circuit board and its battery cell. (It's advisable to insert an

on/off switch in the circuits to economize energy.) On the RS itself, I just fixed the battery with double-sided adhesive tape on the RS's back.

For the helmet, I used a section of expanded polyurethane foam sheet — about 5 mm thick. It is easy to bend, glue, and paint and it is very light, which is an important quality here. I painted it with several layers of black matte acrylic and put on a pair of super-bright blue LEDs (which I wired in parallel, instead of the red back-up LED on the receiver, so they light when an order is received). I fixed the helmet securely on the RS with black electrical tape.

As you can see from Figure 9, it is now possible to control two independent RoboSapiens at the same time in the same place. Let's the games begin — and happy hacking! **SV**

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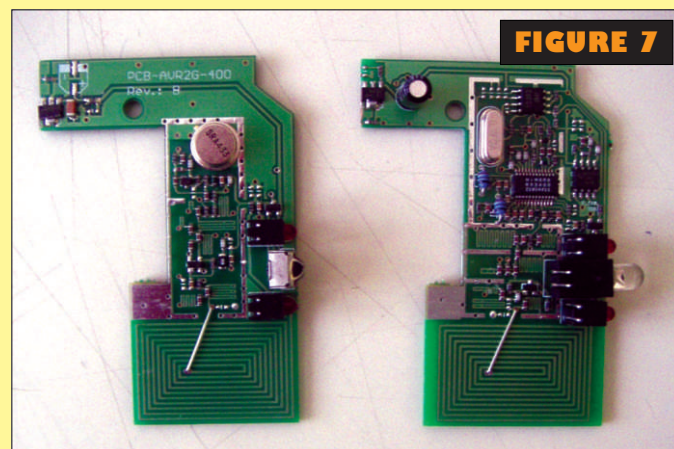
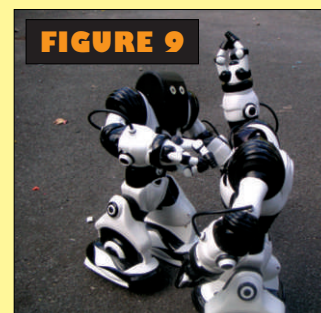
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**FIGURE 7****FIGURE 8****FIGURE 9**

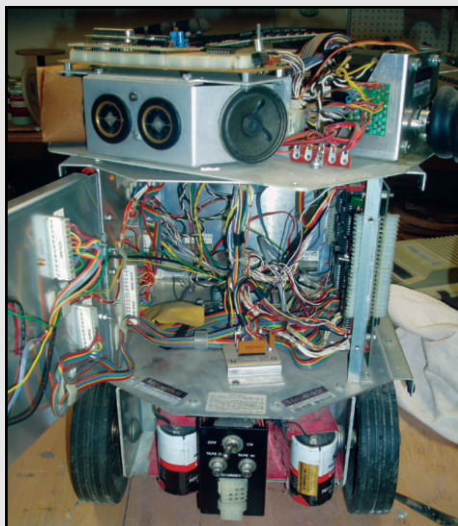
WORKING WITH METAL

by Tom Brusehaver

Before *SERVO Magazine* was launched, I wrote an article on working with metals for the second edition of *Nuts & Volts Amateur Robotics*. This article will contain additional information on that subject, with some necessary, repeated information.

Many robots are built using metals. For non-combat robots, aluminum is an excellent choice, being light weight, readily available, and easy to work with. Steel is used where strength is required, although tempered aluminum can often be equally strong for the same weight.

Aluminum can be worked using many common tools. Even wood working tools can be used for cutting and drilling. Some other slightly specialized tools will make working with aluminum easier.



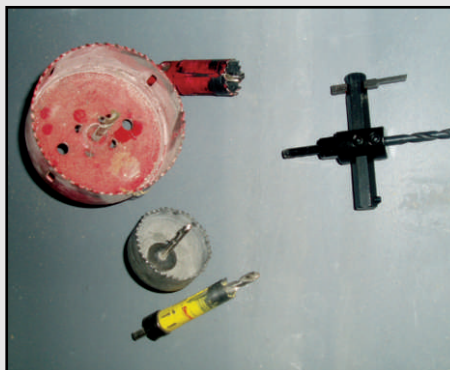
The Hero was designed with an aluminum interior, using extruded parts and sheets.

Safety

When working with metals, safety is paramount. Metal chips can fly almost anywhere. Safety glasses are a must. When using power tools, read and understand all instructions. Hand tools can be as dangerous as power tools if used improperly.

Layout

Before cutting any metal, make a template or at least a plan for the final project. Cutting paper or cardboard is easier and cheaper than cutting metal. Start with a rough sketch, then make a final plan. Cut the paper, drill the holes, and see if the pieces still fit. Take the paper and trace the parts out of metal



Aluminum can be cut with a basic hole saw or an adjustable fly cutter (center bottom).

using a thin marker.

After doing this layout, all the final cuts and shaping should be done. Cutting outside the line is probably the safest in complicated or critical areas. Filing or grinding down to the line is safer than cutting right to the line. It is more convenient to drill all the holes in a sheet before bending, whenever possible; sometimes, bending will change the position of the holes.

Choosing

The choice of aluminum sheet is best made with experience. A 6" to 12" robot could easily be made with a 0.025" to 0.032" sheet. A larger body will need thicker aluminum. Thinner aluminum can be used for a skin or to add stiffness or strength. Using a flat sheet isn't very strong, but bending a thin sheet will actually stiffen the metal. Thinner sheets can be used with extrusions for stiffness. Thicker sheets can be used where the extra



Tin snips and aviation snips are color-coded to indicate cutting direction.

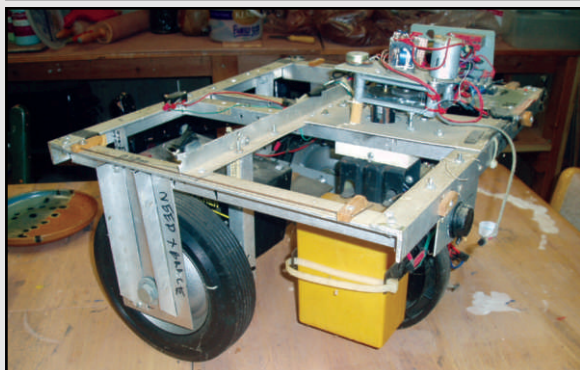
strength is needed or where fasteners or bearings may be used.

An open frame can be built using angle extrusions or tubing. Angle extrusions are usually easier to work with; having no flat surfaces to drill or bolt to is easier than working with round or square tubing. Tubing and angles can easily be used in combination. Extrusions can also be used for building a frame to be encased in sheet metal.

Cutting

When cutting aluminum, using the proper tools is mandatory. Thinner sheets can be cut with shears. Thicker metal must be cut with a saw, nibbler, or grinder. Long, straight cuts in thin sheets can be made with a sheet metal shear or tin snips. Curved cuts can be made with aviation snips: red for cutting left, green for cutting right, yellow for cutting straight. A tin snip will usually be longer, allowing straighter cuts. If shears are available, they are excellent for cutting large sheets into smaller pieces.

A robot built from angle extrusions. Two screws at each corner hold it together. The extrusions are reinforced for wheel mounts.

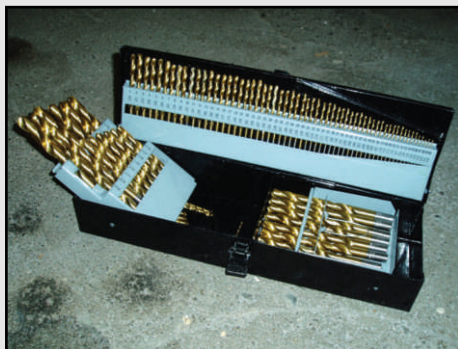


A variable speed band saw.

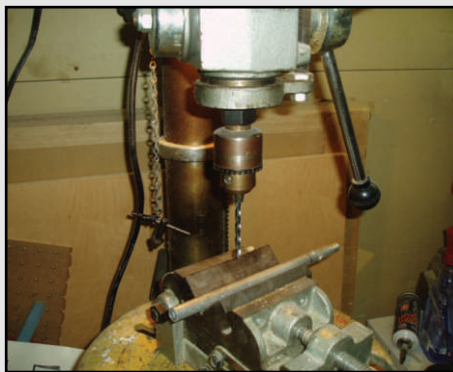


A hand seamer, used for smaller sheet bends.





A full set of numbered and fractional drill bits can be gotten fairly inexpensively and makes operations like tapping easy.



Drilling with a drill press should be done with a clamp. Drilling tubing is easier with a V-block for centering.



A Unibit will drill round holes where a regular bit will make an oblong hole.

For cutting thicker metals — over 1/16" or 0.063 — a saw will be needed. A hand saw — such as a hack saw — will be fine for smaller straight cuts, like cutting extrusion. For making long or curved cuts in sheets, a power saw is usually the best choice. A band saw will allow control while cutting. Larger, thicker metal pieces can be cut with a power miter saw. A saber saw will work great, if nothing else is available; it'll just be harder to keep on the line. Grinding wheels could also be used for cutting extrusions or sheets.

Almost any saw blade can be used for cutting aluminum. Keeping two or more teeth on the metal is the minimum. The more teeth, the quieter the cut. Wood cutting blades can be used for cutting aluminum. A band saw with 16 teeth per inch will cut 1/8" sheet metal. Coarser blades can be used, but the saw will be more difficult to start and control. If the blade speed can be controlled, keeping it slow will keep the blade cool, making it last longer.

Cutting inside holes is a little more difficult. Nibblers and saber saws can be used. Drill a starter hole in the center of the area or a corner and cut from there. A saber saw will require that the part be clamped to the table. For shaped holes — such as squares, keyholes, and circles — punches are available in various sizes and shapes.

After any cutting, shearing, or sawing, the edges of the metal should be deburred. These edges can not only cut skin very easily, but can also be the start of a crack or other failure. Slivers are also common on circular cuts. Using

a file is the best tool to deburr the edges of a cut, although specialized deburring tools are available. A simple half-round bastard file will be the most useful; use the flat side for straight cuts and the round side for curved cuts. Recently, some metal cutting services have been offered. The purveyors appear to be shops offering both an inexpensive (or free) CAD type package; most will also take your CAD output and return the finished parts to you. This could be quite a nice service to take advantage of, especially for more complex parts.

Bending

Bending aluminum is easy, if done

correctly. Pure (1001) untempered aluminum can be bent to almost any angle and radius. Tempered aluminum (i.e. 2024-T3) must be bent with a minimum radius, which varies with thickness. The minimum radius for thinner tempered aluminum (1/16") is about equal to the thickness, but thicker tempered aluminum (1/4") has a minimum radius of roughly twice the thickness.

There are some special tools that make bending the aluminum easier. Bending brakes are useful for long, straight bends; hand seamers are good for smaller bends; bending blocks are useful for thicker material. Hammers are sometimes needed for bending thicker parts or compound bends. A

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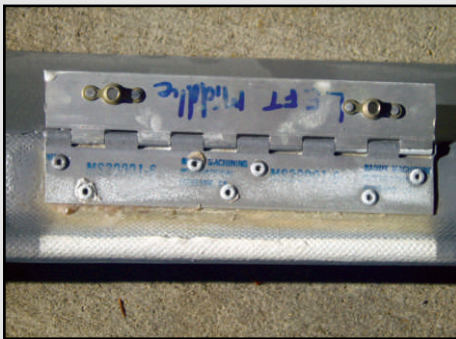
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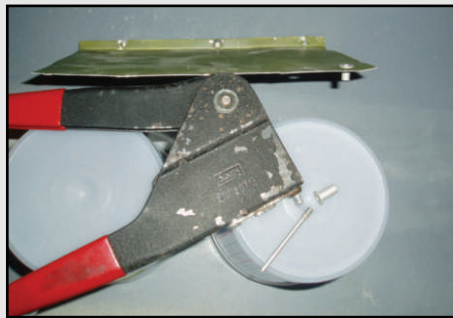
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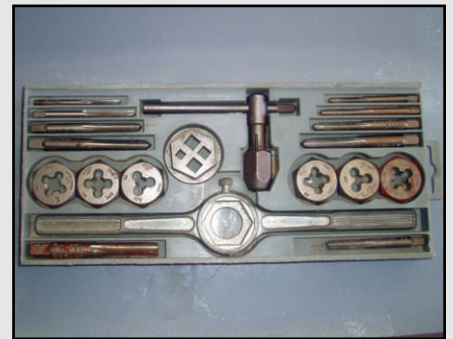
WORKING WITH METAL



The hinge is attached using pulled rivets and solid rivets holding nut plates.



Riv-nuts are installed by threading an arbor into the hole and pulling it, like a rivet. The arbor is removed and a threaded hole remains.



A complete set of taps and dies will be very useful at various times for different projects.

bending brake is available for small sheets — from 12" to a few feet. The 12" ones can be purchased for under \$30.00 and are attached to a bench. Floor standing brakes are larger and are often available at surplus outlets. The larger ones should have a setback setting for the radius of the bend. A brake can be made using a couple of pieces of hinged wood clamped into a vice.

Small bends can be made with a hand seamer, available in sizes from about 2" to 8". Because a hand seamer has a limited depth, bends are limited to about 2" or less, depending on the tool. In cases where complex bends are required — making the use of a brake alone too difficult — the hand seamer will allow you to make bends in tight areas.

Thicker metal bends can't be bent with a seamer or brake. A bending block with radius edges and a hammer will allow for proper bends. Use a clean hammer to minimize scratches. Make even bends, working from the clamped end to the unclamped end, so the

metal's stretch can be managed.

Usually, bending will stretch the metal. It won't stretch far — just a little. Working the metal longer will stretch the metal more. The stretch can be used, especially when bending compound curves. The metal will have a grain that can be seen if you view it at an angle from the side. Aluminum bends easiest perpendicular to this grain.

There are many tools for bending curves into metals. When cars are built, they use large presses to stamp out the finished part in a single squeeze. At home, the metals can be formed with careful hammering. A leather bag and a curved hammer can be used to carefully form a compound curve. English wheels and power hammers are sometimes used at home, but they are large and most people don't have them. With care and time, the manual tools can do everything the big tools can.

Drilling

Almost all fastening will require

drilling a hole for the fastener. Sometimes, there are other reasons to drill holes in the metal, including running wires and clearance for moving parts. Using a high quality, sharp, high speed steel (HSS) or cobalt drill bit will produce the best results.

Drilling metal can be a little dangerous. The metal must be fastened, either in a vice or by clamping it to the bench. Holding the metal in your bare hand risks injury. When the drill bit is almost through, it will grab and might cause the part to spin on the bit, causing the ends to swing wildly or fly in some direction off the work surface.

Drilling thin sheet metal will require a backup structure to minimize deformation. A block of wood makes a great backup structure, since it allows the bit to drill through the metal without damage. This will still allow the drill to tear through the final bits.

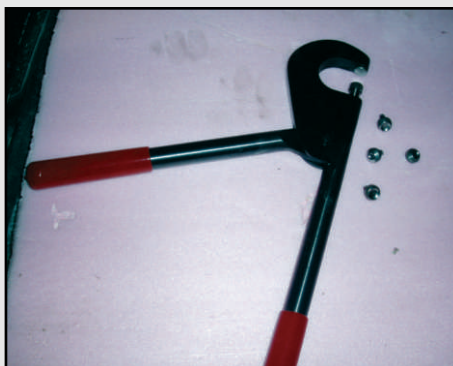
Fastening

Joining sheets can be done with

The clecos will temporarily clamp the metal together. Both side clamps and drilled clamps are shown with their special pliers.



A rivet squeezer and dies for forming the rivets.



A good set of files: round, half-round, and rectangular.



screws or rivets. Rivets are best for permanent joints. If there is ever a chance that the joint will need to be opened, use screws. For structural joints, machine screws are better than sheet metal screws. A good rule of thumb is to use a screw or rivet that is about twice the diameter of the sheet thickness when working with sheets up to about 1/8".

Welding aluminum can be done, but it takes planning; not all aluminum alloys can be welded, either. Tempered aluminum will lose its temper when heated, causing uneven stress points. Usually, a special flux will be needed to make a clean joint. There are aluminum repair rods that can be used to attach similar pieces of aluminum. These rods function similarly to brazing rods and can be used with a simple propane torch.

To make screwing sheets easier, nut-plates or riv-nuts can be added; they make repeated fastening less work. Nut-plates are available in various configurations: straight or angled, usually with one or two ears. The nutplate is fastened to the sheet with rivets. Riv-nuts are similar, but are attached using a rivet puller — similar to pulled rivets.

Thinner metals cannot be threaded, but thicker metal (>1/8") can be. Threading a hole in the metal will allow screws or bolts to attach without a nut. Threading is done using a tap after drilling the proper sized hole. While tapping a hole, it is important to keep the tap cool by using a lubricant. Turn the tap until it slows, then remove the tap, clean it off, and repeat until tapped through. There are special taps for holes that don't go all the way through metal. Dies can be used to thread rod, if there is a need for this special connector.

Hinges can also be used to join sheets and will add stiffness. Using a long, piano-type hinge will stiffen the whole sheet. The hinge can be used as a hinge, fastener, or joint. If the hinge pin is replaced with a longer wire, it functions as a fastener to hold a sheet in place opposite another hinge.

Using countersunk rivets or screws will require extra work. The clearance hole will need to be drilled. The countersink bit will open up the top sheet so the head will be flush with the top. Smaller screws or rivets can be

used with countersunk holes. If a larger fastener is used with thinner sheets rather than countersunk holes, the metal should be dimpled.

Rivets are excellent fasteners. They are easy to work with and inexpensive. Solid rivets only require that you drill a hole, insert the rivet, and mash the end. Pulled rivets — sometimes called pop rivets — only require drilling a hole, inserting the rivet, and pulling the shank with a special tool. There are tools that help with solid rivets — such as squeezers and guns — but a simple hammer and punch can also be used. Rivets are generally permanent, but they can be drilled out.

When attaching pieces together, it is sometimes easiest to drill the holes with temporary fasteners to make sure that all the holes line up. Using a screw and a nut will work, but it will take time to get the screw in and take it out. Deburring is a good idea, so you should plan on taking the parts apart.

Another temporary fastener is the cleco. Clecros are available in various diameters and will grab thin sheets up to almost 1/2" total thickness. Clecros also require special pliers.

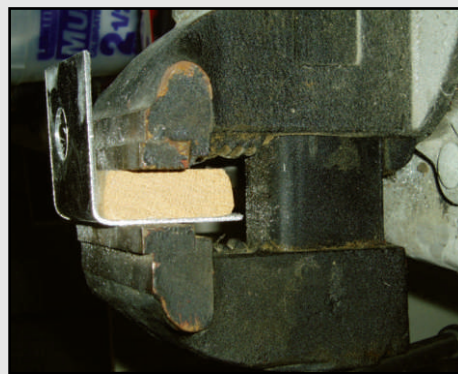
Finishing

Making a professional-looking, long lasting part requires some special techniques. Finishing the parts will add to their length of usefulness by protecting against corrosion and cracking. Paint or primer will minimize corrosion by providing a protective barrier against the elements.

When cut, metals have cut marks that can become stress points and can lead to cracks. Filing the edge of the metal with the file perpendicular to the metal will quickly remove the cut marks, leaving a smooth edge.

Files are great tools; getting a proper one is necessary to do a good job. A half-round bastard file will be the most useful and a small to medium coarse one will be used on sheets. Heavy metal cut with a bandsaw can be smoothed with a coarse, flat file. Round holes are best filed with a round file. Triangle files are good for getting into corners.

Be sure to protect the metal from



For bending heavier metal, use a bending block that allows spring-back.

moisture or other corrosive factors. Some sheets are protected with a coating on one or both sides. To maximize the protection on sheets of aluminum, there are chemicals that can make the protection permanent. Alodine is an excellent protectant, but you need to use alumaprep first. Anodizing the metal will add a pleasant color and protection. Once primed, the aluminum can be painted.

Summary

Fabricating robot parts yourself can be done easily. Many times, the robots built need something special that can only be gained by using these simple techniques. With practice, many of these techniques can be utilized in everyday applications. **SV**

RESOURCES

Most larger cities will have metal supply companies. Check your telephone directory.

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RELAY CONTROLS

by Steve Schmitt

Most robots use medium-sized DC motors with voltage and current ratings of 12 to 24 volts and 10 to 100 amps. If variable speed is not required for controlling a motor, a relay controller is less expensive than an electronic speed controller. A relay controller can be as simple as one on/off relay or four relays in an H-bridge arrangement for forward and reverse control. In either case, a relay controller should be as reliable as an electronic controller. However, it is not practical for controlling large motors or small motors, as large relays cost too much and small relays draw almost as much current as the motors they are controlling.

Designing a good relay circuit

requires some knowledge of how relays work. The circuit shown in Figure 1 — which I have seen published in magazines — will destroy a relay in a very short time. In fact, it may even weld the contact within the first few cycles. This is most discouraging, but will never happen if the design suggestions in the following paragraphs are utilized.

Relays can be purchased from many suppliers for a few dollars each. If they are bought in quantities of 10 or more, the cost should be under \$2.00 each. The VKP-15F42 is a standard type relay that is readily available and can control motors of the size used for automotive heater fans. It is an SPDT relay and is nominally rated at 40/60 amps with the NC contact rated at 40 amps and the NO contact at 60 amps.

Another standard type is the VF7 series automotive relay, which is the standard 1" cube type with either PC board connectors or 1/4" quick connect terminals. It is an SPST relay rated at 75 amps that can tolerate an overload of 420 amps for 0.15 seconds and control motors such as the EV Warrior. For larger motors, the best is the Ford starter motor relay, which can

switch upward of 1,000 amps.

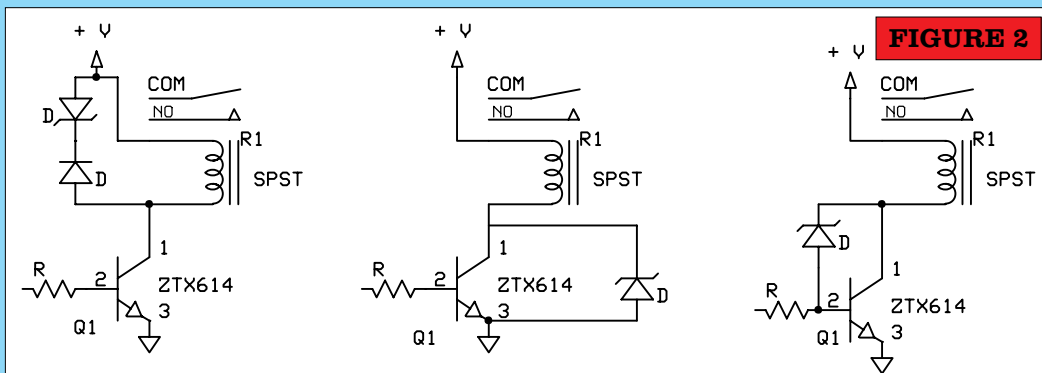
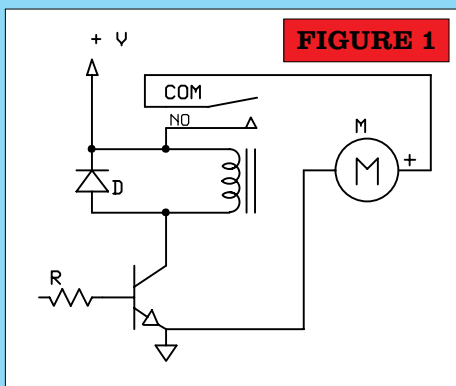
Since the automotive industry uses a huge number of relays, most suppliers will have a good stock of VKP-15F42 and VF7 relays. One word of caution: Be sure to get name brand relays, as there are many low quality knock-offs being sold on the auto market.

When designing a relay circuit, there are three main areas of operation that have to be considered: 1) closing the contacts, 2) continuous load, and 3) opening the contacts. By far, the most critical is opening the contacts, as that is where most failures occur.

When the contacts close, the first point of contact is subject to the full load and instantly melts or even boils. This is the start of an arc that melts the high spots away so more area can make contact. Eventually, the two relay contacts are forced together and a large enough area is brought into contact to carry the current load. The two relay contacts are lightly welded together, but are easily broken apart by the spring action of the relay. Even under a large overload, the spring will be able to overcome the weak weld.

After the two relay contacts are brought together and they are lightly welded, the relay can carry continuous current. Since there is some contact resistance, a large overload will cause the relay contacts to heat. This heating may be localized and cause more melting of the contacts.

In the case of the VF7, the allowable overload is 420 amps for 0.15 seconds or six times the



relay rating. Note that this rating is the manufacturer's rating and is based on 100,000 operations. They do not have a rating for a catastrophic failure.

Lastly, when the contacts open, several things can happen that either reduce the life of the relay or even cause a catastrophic failure. An arc can form that will cause material to be transferred from the cathode contact to the anode contact. This causes burning and pitting, which will eventually lead to complete failure. However, while the life of the relay is shortened, it will have a predictable life. If all that is needed is 1,000 operations, a large amount of arcing can be tolerated.

The most destructive thing that can happen on opening is that the contacts can actually weld shut and not open at all. This occurs when the armature does not accelerate to a high enough speed to break the light weld. Also, if the contacts open so slowly that they bounce and an arc is present at the same time, the contacts will weld.

Generally, the contacts weld during opening, not closing. Referring again to the circuit shown in Figure 1, the shunt diode will cause the magnetic field in the relay coil to decay slowly and, therefore, the contacts will open very slowly. The result will be either welded contacts or greatly reduced life.

When opening the relay, some sort of coil suppression is needed to suppress the inductive surge from the relay coil. Without any suppression, the surge may be several thousand volts — which makes the relay open very fast, but will destroy any driver transistors.

The best way to suppress the coil is with a zener diode (Figure 2). When

Material	Arc Voltage	Arc Current
Cadmium	10	0.5
Copper	13	0.43
Gold	15	0.38
Nickel	14	0.5
Palladium	15	0.5
Silver	12	0.4
Tungsten	15	1.0

From: Application Notes, Tyco Electronics Corp.
www.pandbrelays.com

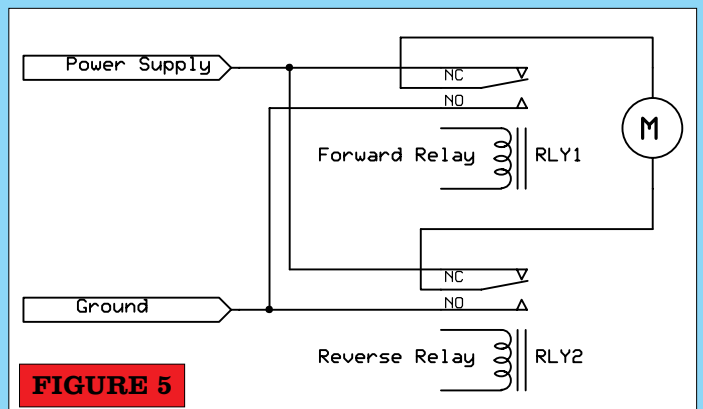
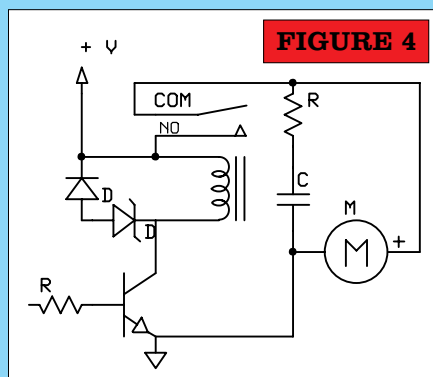
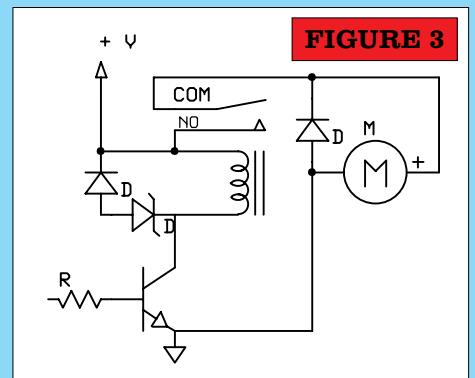
TABLE 1. Various arc voltages and currents.

the zener diode is connected across the driver transistor, its rating is the desired surge voltage plus the power supply voltage. The zener diode should have a voltage rating high enough to cause a surge voltage of at least 30 to 50 volts for a 12 volt relay.

Since the current and power ratings required for the zener diode are not changed by the surge voltage, the highest possible voltage should be used. With a zener diode shunt, the drop-out time for the relay will be almost as fast as an unsuppressed relay. Tyco Electronics gives a time of 1.5 ms for an unsuppressed relay and 1.9 ms for a zener diode shunted relay. While there are many other ways to shunt the coil, a zener diode causes the magnetic field to decay the fastest.

The key to long relay life is to control the contact arcing and use good coil suppression. Coil suppression is a matter of

design, but controlling arcing may be difficult or even impossible. The problem with controlling contact arcing is that DC motors are inductive and can draw large currents that defy any snubber circuits. The other problem is that the supply voltage is usually 24 volts or higher. Table 1 lists arc voltages and current values for several common contact materials used in relays. To have no arc, the



RELAY CONTROLS

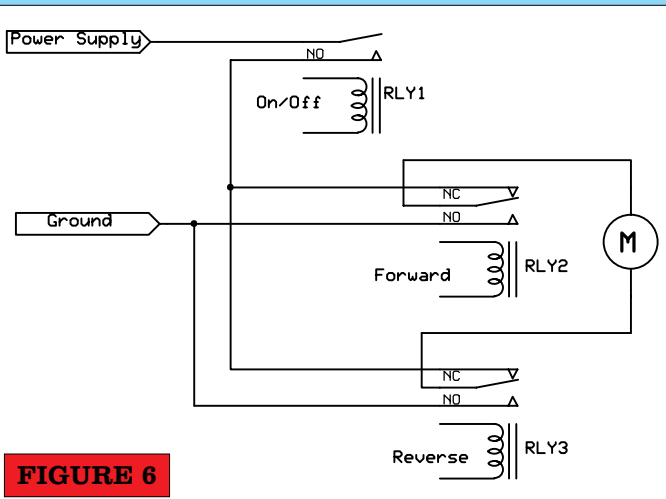


FIGURE 6

voltage or current at contact opening has to be less than the values given in Table 1.

The voltage across the relay contacts at opening is either the arc voltage or available voltage – whichever is less. The available voltage is the voltage that would be present at the contacts if there was no arc. If the available voltage is greater than the arc voltage, an arc will ignite if given a large enough current.

If the power supply voltage is less

than the arc voltage, the best way to snub the relay contact is with a shunt diode across the load, as shown in Figure 3. When the supply voltage is less than the arc voltage, a diode snubber will insure that there is no arc when opening the contacts. When the supply voltage is higher than the arc voltage, the shunt diode will do very little because the available contact voltage during opening will be the supply voltage plus the diode forward voltage drop of .7 volts when opening. Before the shunt diode starts to

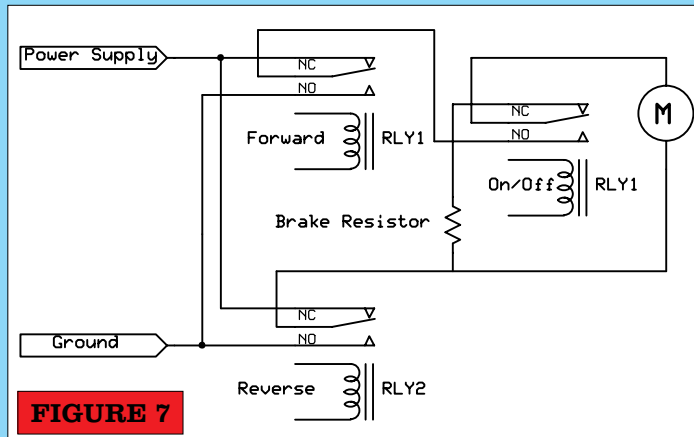


FIGURE 7

conduct, an arc will form and the diode may never conduct.

Assuming there is no shunt diode or snubber across the relay contacts, the available voltage at contact opening is the supply voltage minus the back EMF of the motor plus the inductive surge.

At stall, the back EMF is near zero and the load current is maximum. At no-load, the back EMF is nearly equal to the supply voltage and the load current is near zero. Therefore, at no-load, there will be little or no arcing; however, at stall, there will be significant arcing.

A typical snubber for a bi-directional motor control circuit consists of a resistor and capacitor, as shown in Figure 4. The resistor is chosen to have a voltage drop of about one-half the supply voltage at maximum load current. Assuming a 24 volt supply and 70 amp stall current, the resistor value would be 0.17Ω . This is probably less than the internal resistance of the snubber capacitor and battery pack, so no resistor is needed.

The snubber capacitor has to be large enough to suck up the 70 amp inductive surge long enough for the contacts to open while keeping the contact voltage less than the arc voltage. Generally, any capacitor large enough to snub out the opening arc will damage the contacts on closing. The best solution is to assume a

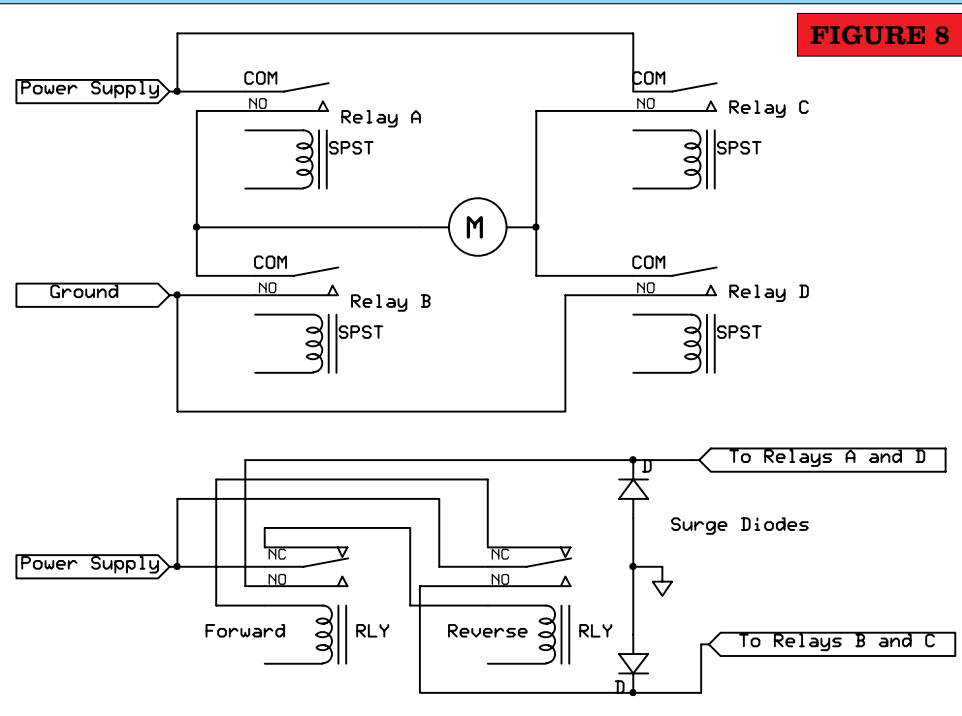


FIGURE 8

short relay life and buy the relays in bulk. A 10 μF snubber capacitor can be used to eliminate some arcing and prolong the relay life. I have noticed that few — if any — relays used in automobiles have a snubber across the contacts.

Both the VF7 and VKP relays have a maximum switch rating of six cycles per second under load, which is high enough to perform speed control in many applications. A model boat with a 6 volt supply and a diode snubber would work very well with a relay speed controller. A combat bot with a 24 volt supply and no snubber would not be a very good application of a relay speed controller. I did build a combat bot with a relay speed controller and it worked quite well for about half an hour of run time. After that, the relays had to be replaced.

In general, it is not a good practice to control one relay with another. For example, if relay A were to control the coil of relay B, it would be impossible to get a surge voltage of 30 to 50 volts on the coil of relay B to make it open fast. The inductance of the coil on relay B will cause an arc to ignite at the contacts of relay A and the surge

voltage will be limited to the arc voltage. Also, the contact arcing on relay A will greatly reduce its life. A surge diode can be used to prevent arcing at relay A, but that will further slow the opening of relay B.

To make the diagrams simpler, in Figures 5-8, the coil suppression and drive circuits are not shown. In most cases, the coil suppression and drivers will be similar to Figure 2.

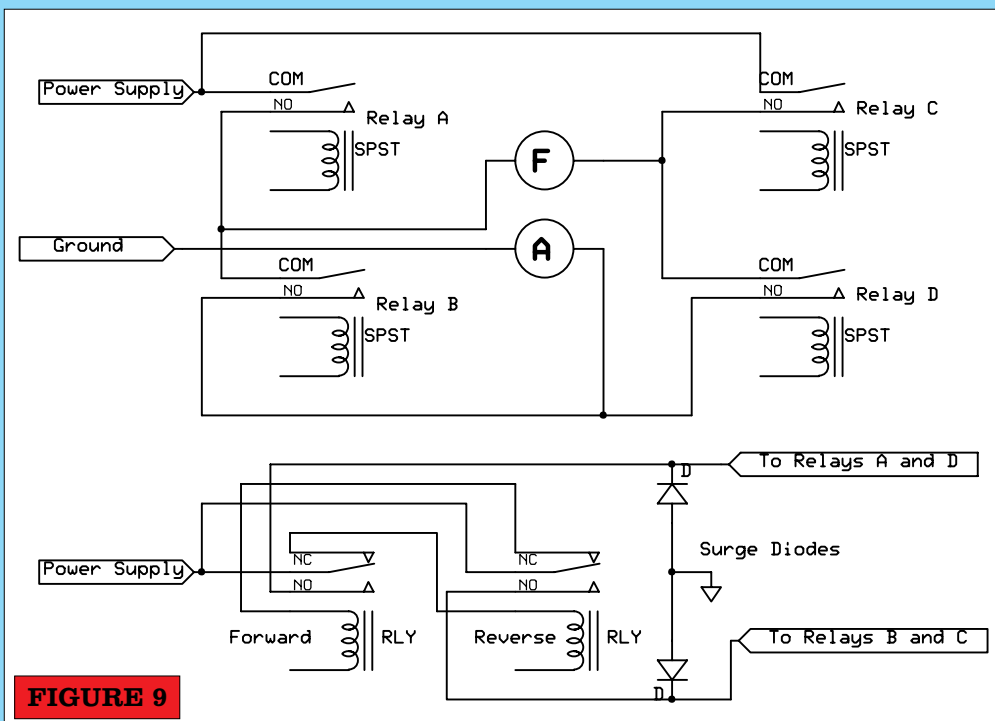
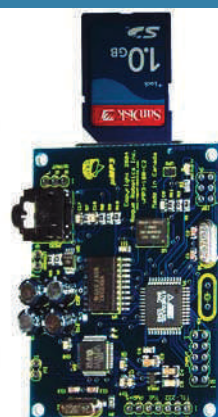


FIGURE 9

Figure 5 shows a two relay circuit for controlling a bi-directional motor. Since it is not an H-bridge, there is no way for the power supply to be shorted. All states of the relays are safe. A relay such as a VKP-12F42 can be used to control motors the size of an automotive heater fan motor with a 24 volt power supply.

Figure 6 is very similar to the previous circuit, except that an on/off

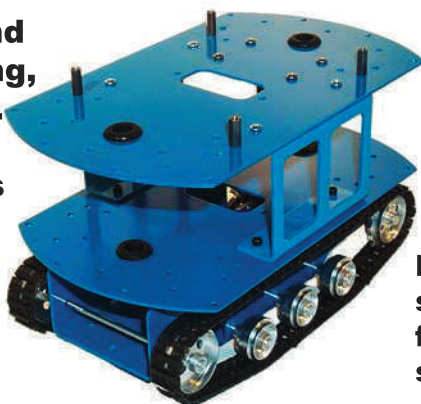


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RELAY CONTROLS

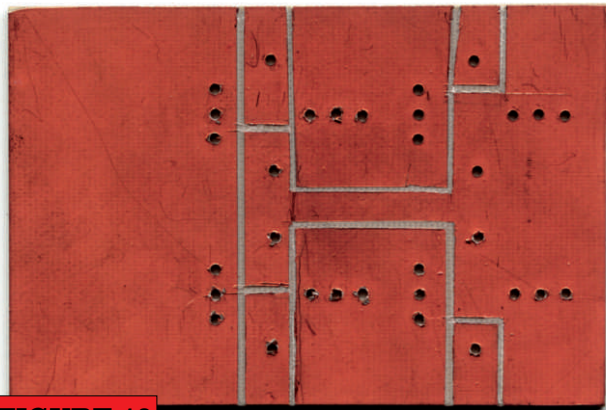


FIGURE 10

resistor across the motor when it is not powered. This puts an electrical load on the motor and causes it to decelerate quickly. A possible use would be on a four wheel, skid/steer robot with a drive motor on each side. When one motor is driving and there are no break resistors, the robot will turn in large

relay has been added. In operation, the desired direction relay is set and then the on/off relay turns on the power.

To stop the motor, the opposite direction relay is activated and — after the circuit is broken — the on/off relay is released. Then both direction relays are released to return to the starting state. The objective is to always break the circuit by turning on a relay. This is the best way to prevent welding the contacts.

Another variation of the circuit is shown in Figure 7. In this circuit, the on/off relay is not intended to turn the motor on or off; instead, it puts a brake

circles, but — with a break resistor — the turns will be much tighter. Another use is when the relays are pulsed for speed control. Without any load, the motor will tend to run at its no-load RPM, regardless of the pulse rate. The break resistor puts a load on the motor and keeps the RPM closer to the desired speed.

During deceleration, the motor is a generator and the value of the resistor is selected to maximize the electrical load. Since the optimum value depends on RPM, the best value is to match the impedance at about 50% to 75% of the working RPM. The impedance is the generator's open

circuit voltage divided by its short circuit current.

The next circuit (shown in Figure 8) uses relays to control other relays. Relays A through D are Ford starter relays that control large motors. Starter relays are designed to operate with a shunt diode across the coil and will never weld.

However, they are rated at only 12 volts. The forward and reverse relays are standard 20/40 amp automotive relays. Note that the control relays are cross-wired so that only one can be picked at a time. This circuit works because the 12 volt supply voltage is less than the arc voltage and the large motor is assumed to have very little inductance.

The circuit shown in Figure 9 shows how to control a series-wound starter motor using Ford starter relays. A series-wound motor cannot be reversed by just inverting the input polarity. The field winding has to be isolated from the armature and the motor is reversed by transposing the polarity of only the field winding. In most — if not all — starter motors, one set of brushes is hard-wired to ground, so it is very difficult to isolate the armature from ground.

Figure 10 shows a PC board for mounting four VF7 type relays in an H-bridge arrangement. The PC board was "etched" using a razor blade and straight edge. All the wires from the battery pack and to the motor are soldered to the surface of the PC board without holes, as the current loads require a large copper area under the solder connections. Note that the relays have three power pins per contact to carry the 70 amp loads.

We use custom transmitters with push-buttons to control the robots with relay motor controls. Relays are on/off devices, so the human interface must also be a simple on/off type control, rather than a joystick or some other analog control interface. Those control interfaces can make it very difficult to drive a robot with a relay control system. **SV**



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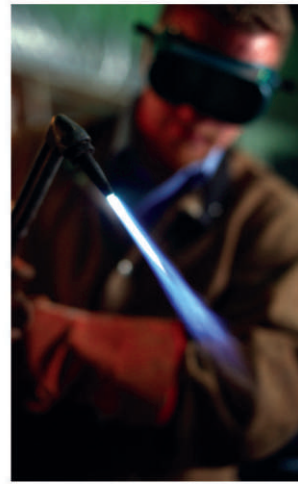
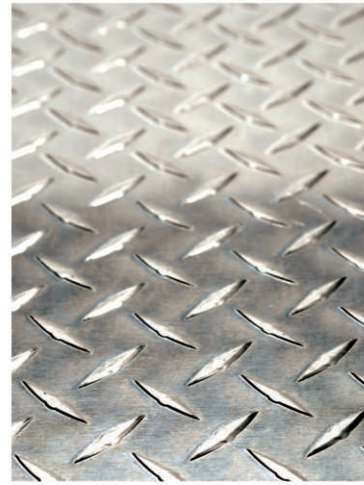
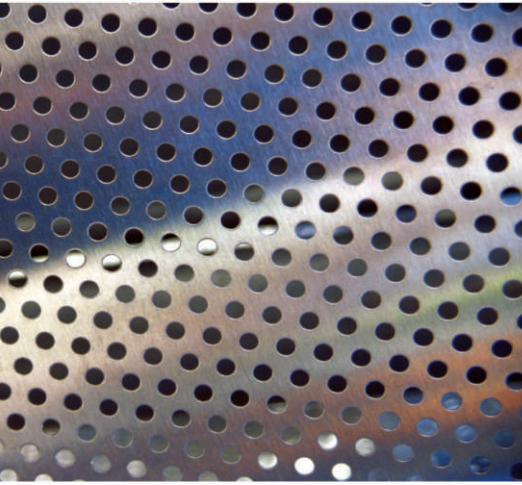


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METALWORKING 101



Welding, Brazing, and Soldering

by Gordon McComb

Some lament the end of “Detroit Metal” — the days when American cars used tons of steel and chrome for the cars of the ‘40s and ‘50s. Don’t let the same thing happen to robots! For a heavy-duty robot, you need to consider metal — if not for the frame or other structural components, then for the body. Most of the winning combat robots are made of aluminum or steel (some are even stainless steel) and could dent a ‘55 Ford if the two ran into each another.

Now, That’s a Robot! Seriously, in this section are sources for and about metals suitable for use in robotics. Several online metal retailers are included, as well as some local establishments that have websites you can look at. Buying metal through the mail can be expensive if you’re purchasing large pieces of steel, as shipping costs mount. Therefore — depending on the material you are purchasing — you may wish to look for a local resource before turning to mail order.

On the other hand, lightweight

aluminum and brass is readily shipped, especially if you purchase it in the sizes closest to your end application. That also limits waste and helps reduce cutting metal to size.

Metal can be joined using glue and fasteners (which include nuts, bolts, sheet metal screws, and rivets). For heavy-duty constructions, however, welding offers the most strength, particularly over long periods of time. Depending on the materials and the application, it may also be practical to braze or solder the metal pieces together.

How Welding Works

Welding is the process of fusing two or more pieces of metal together by melting the base metal. A filler metal — usually the same as the base metal — is added to “build-up” the weld in order to make it even stronger. Given a proper weld, the join can be as strong — if not stronger — than the surrounding metal pieces.

- Welding metal requires very high heats and ordinary flame torches will not do the job. A common all-purpose welding rig for mild steel is the oxy-acetylene torch. This torch uses acetylene as the flammable gas and oxygen as the oxidizer. Together, these gasses produce up to 5,600° F. Oxy-acetylene torches can be used for both cutting through thinner pieces of steel and for welding.

A specialty cutting torch is best used when cutting through steel, as its flame is hotter. While oxy-acetylene welders can also be used with non-ferrous metals, the flame is generally too hot and other types of torches are preferred.

- An arc welder uses a high electricity current to produce a pin-point high temperate spot on the metal. The metal is instantaneously melted by the arc. Many arc welders require 220 volts or higher and the larger units — used by professional welders — run off their own generators. However, there are some arc welders designed for

110 volt use. You are, however, limited to welding fairly thin sheets of metal — down to about 12 or 14 gauge.

- MIG (Metal Inert Gas) welders are used with steel and several non-ferrous metals. MIG welders are an update on the classical arc welder and both use high currents of electricity to join pieces of metal together. The MIG welder adds an inert gas — typically an argon and CO₂ mixture — to prevent oxidation during the welding process.

Most MIG welding rigs use a motorized wire feed, where just the right amount of filler rod is automatically pushed through the torch head. The ease of use of the MIG welder has made it a popular choice among do-it-yourselfers. Shielding gas is readily available from industrial gas outlets. There are some 110 volt MIG welders available.

- TIG (Tungsten Inert Gas) welders are used to join aluminum, steel, and stainless steel — “problem” metals for most of the other welding rigs. Like a MIG welder, a TIG welder uses an electric arc to produce the high temperatures for welding. The inert gas is often a mixture of helium and argon. Successful use of the TIG welder — most of which are engineered for 220 volt or higher operation — is a matter of practice, especially when welding aluminum or stainless steel.

TIG also goes by the name heliarc.

- Plasma torches use a blast of extremely hot air — created by the discharge of a voltage arc — to melt metal. The hot air creates a “plasma zone” where temperatures can reach in excess of 20,000° F. Plasma torches are commonly used to cut metal, including fairly thin sheets. It is not uncommon to see plasma torches attached to a computer for automated cutting.

Using any welder requires that you wear goggles, as the light of the flame (or arc) is exceedingly bright. Arc-type welders (standard, MIG, TIG, etc.) require a darker lens. For all arc-type welders, you should wear a full face mask and long sleeve shirt; the arc produces ultraviolet radiation and you can get a serious sunburn — even if you weld at night! Of course, all welding should be performed using appropriate welding gloves.

About Brazing and Soldering

Brazing and soldering involve temperatures that are far lower than welding. In fact, for both brazing and soldering, the base metal being joined is not melted. Rather, the joint is created using a soft metal that melts at a relatively low temperature. The American Welding Society defines

brazing as working with temperatures above 840° F; soldering occurs at temperatures below 840° F.

Many brazing metals are silver alloys (some have copper and phosphorous added) and are commonly used to join copper plumbing pipe. Many solder metals contain lead and these alloys melt at lower temperatures. Brazing and soldering can be accomplished using simple gas torches. In all cases, the torch is used to heat the metal to be joined, not just the brazing/soldering metal.

- Propane torches produce a flame that is — at its hottest point — about 3,200° F. These are commonly referred to as air/gas torches because they rely on the surrounding air for oxygen. (Air is about 30% oxygen; the bulk is nitrogen.)

- Enhanced gas torches — such as MAPP gas — burn at higher temperatures; MAPP gas torches burn at around 3,700° F. Enhanced gas torches should always be used with an approved torch head because of the increased temperatures.

- Oxygen/gas torches use a separate oxygen tank and propane or other flammable gas. In most cases, the separate oxygen feed increases the flame temperature some 50% over flammable gas alone. A special torch head is required to use oxygen/gas mixtures (see Table 1).

Prior to soldering and brazing, any dirt, oil, or oxidized matter (rust, corrosion) must be removed. This is most readily done with isopropyl alcohol, followed by scouring with a stiff wire brush. The brush also serves to “scratch up” or roughen the surface and increases the surface area. The greater the surface area of the joint, the better the soldering/brazing will hold.

In almost all cases, brazing and soldering requires that flux — a waxy type of substance — be brushed over the surfaces to be joined. Flux is used as a “wetting agent” for the brazing/soldering material and allows it to flow when the base metal is heated to the correct temperature. Without

SHOPPING THE STORE FIXTURE OUTLET

So you can't find the metal you want at the local hardware store, home improvement warehouse, or industrial supply outlet. Have you tried the neighborhood restaurant supply store? Many carry inexpensive sheets of stainless steel, aluminum, and other metals. Sure, the stuff may be intended for use in the kitchen, but it's still perfectly good metal — and is often cheaper than at other sources. Look in the Yellow Pages for local restaurant supply outlets near you.

Another good source for metal doo-dads of different shapes and styles is the store fixture outlet. These cater to retail stores and stock such items as metal poles, hangers, shelving grilles, and

many other useful items. Prices vary depending on the finish of the metal — polished brass is more expensive than basic plated steel.

Here is a small selection of store fixture outlets that offer mail order shopping. Browse their web pages to see what they have to offer.

Alpha Store Fixtures, Inc.
www.storefixtures2000.com

Display Warehouse
www.displaywarehouse.com

Tebo Store Fixtures
www.tebostorefixtures.com

flux, the brazing/soldering metal will just clump to the base metal, making for a very poor joint. Be sure to match the flux with the brazing/soldering material you are using.

“Welding” Aluminum

Aluminum can be welded using a MIG or TIG torch or by the skillful use of an oxy-acetylene or arc welder. Most weekend robot builders will use a brazing method to join aluminum instead. Brazing is acceptable if high strength is not required. (For example, you will want a full welding job if you plan on entering your robot in a *BattleBots*-style combat event.)

Aluminum brazing involves the use of a hot bond alloy that melts at about 850° F (aluminum starts to melt at about 1,200 to 1,400° F, depending on the alloy). The bonding alloy joins to the aluminum by surface adhesion (like a glue), not by welding. A regular propane or MAPP gas torch is sufficient for brazing aluminum.

Welding Gas Safety

Acetylene, propane, and MAPP gas are highly flammable and quite dangerous when used carelessly. For obvious reasons, do not smoke when working with gas torches and keep

Gas	Flame Temperature With O ₂ (°F)	Cylinder Oxygen to Fuel Ratio	Pinpoint Heat Concentration
Acetylene	6,000	1-1	Very high
MAPP	5,300	2.5-1	Fairly high
Propane	4,800	4-1	Low

TABLE 1

them away from any source of open flames. It's also a very good idea to store them separately from any flammable materials, especially cloth and motor oil.

Purchase welding gas only as you need it. Do not store it. If you've rented your oxy-acetylene tanks and you will not need them for a while, return the cylinders to the industrial gas outlet.

Welding gas has a characteristic smell, but in low — yet still dangerous — concentrations, a gas leak may go unnoticed. If the concentration ignites, it could cause a serious fire or even an explosion. Keep the following in mind:

- Acetylene is lighter than air, so it rises. Avoid using an acetylene torch indoors, where any leaking gas may collect near the ceiling.
- Propane and MAPP gas are heavier than air, so they sink. Any gas concentration will be near the floor, which is also where most pilot flames (from water heaters, etc.) are located.

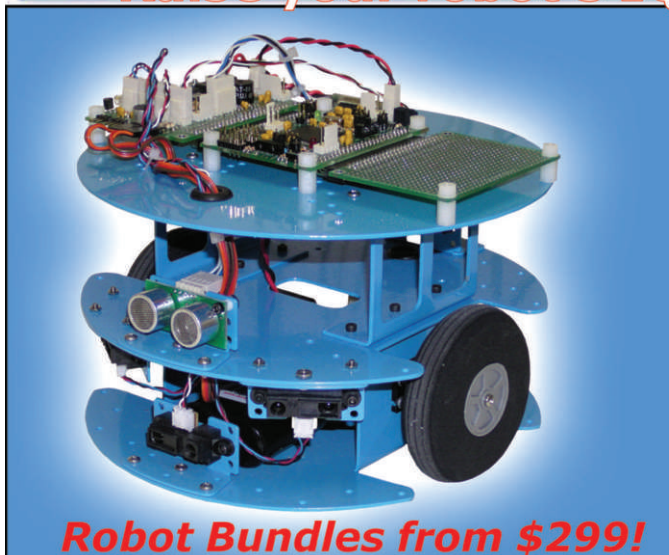
In both cases, adequate ventilation is required to disperse any gas leakage.

Buying Welding Equipment Online

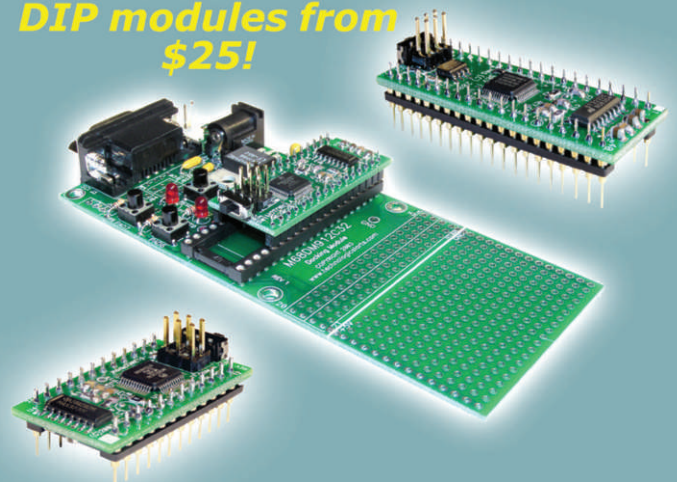
You can purchase welding equipment and supplies — as well as the metal stock — online. A number of online resources for metals and welding supplies are provided in this column. Keep in mind that welding gear — as well as the metal itself — can be heavy, so consider the extra cost of shipping. Be sure to also check out local sources for metal supply and welding outlets. Look in the Yellow Pages under both “Metal” and “Welding.”

Note that welding gasses and other flammable material cannot normally be shipped by the US Post Office, UPS, FedEx, or other so-called common carriers. Though some online welding supply retailers offer delivery of welding gasses to local customers, you will find it much easier to simply purchase

Raise your robot's IQ with Motorola's 9S12!



DIP modules from \$25!



www.technologicalarts.com

the gas from a local welding shop.

If you don't already own a gas cylinder, you can either buy or rent one when you purchase the gas. Be sure to add the price of a cylinder or cylinder rental when calculating the costs of your welding endeavors. When the cylinder is depleted, you return it for a freshly filled one.

Online sources are an ideal way to comparison shop for the "consumables" used in welding, soldering, and brazing. Consumables are anything that is depleted during the welding (or soldering or brazing) process. An example of a consumable is the spool of wire used in MIG welding or the rod used in gas welding or brazing.

Sources

The following sources sell welding supplies and/or metal, either by mail order or at retail stores. Some of the metal supply sources listed here don't ship mail order, but they provide useful technical information on their web pages. All of the welding supply sources are geared toward the consumer, rather than commercial welding. As such, most are aimed at

the automotive enthusiast.

Admiral Metals

www.admiralmetals.com

Online (and local outlet store in Woburn, MA) metals supplier.

Sells full lengths and cut pieces. Rod, bar, tube, sheet, and plate in: aluminum, brass, copper, bronze, and stainless steel.

Airparts, Inc.

www.airpartsinc.com

Metal supplies: fasteners and hardware, aluminum and steel sheets, rods, tubes, etc. An excellent source for aluminum, chromolly, and other home-built aircraft construction supplies. You don't need to build an airplane; a robot will do. Large selection of aluminum extruded pieces, including rods, angles, bars, and tubing. For many of the products, the aluminum allowance (such as 6063/T52 or 6061/T6) is specified.

All Metals Supply, Inc.

www.allmetalsupply.com

All Metals is a distributor of ferrous and non-ferrous metals, fasteners, and industrial hardware. Metal products include aluminum, copper, zinc, and

other metals in bar, tube, extruded shapes, sheets, and plate. Fastener products include machine screws and bolts of all sizes in stainless, zinc, and nylon. The web page is for reference only; order directly from the company.

America's Pride

www.americasprideonline.com

Geared for the automotive repair business, America's Pride sells a number of wire (TIG and MID), plasma, and arc welders, plus accessories and consumables. Several of their welding kits are designed for use with 120 VAC.

ASAP Source

www.asapsource.com

Offers aluminum, brass, and steel rods, bars, sheets, plates, and extruded forms. Sold in various sizes and lengths. Available in special cut lengths for an additional charge. Also sells threaded rod, welding rod, acetal, and acrylic plastic pipes, rods, sheets, and plates.

Atlas Metal Sales

www.atlasmetal.com

Suppliers of casting ingots (aluminum, bronze, pewter). Billed as "Your Art Sculpture Specialists." Also sells silicon bronze, rods, sheets, plates, and tubes, plus copper sheet and coil.

Cal Plastics and Metals

www.calplasticsandmetals.com

Plastics and metals. Metals offered (in various shapes, including sheets, bars, and tubes): brass, bronze, copper, aluminum, and stainless steel.

Du-Mor Service & Supply Co.

www.du-mor.com

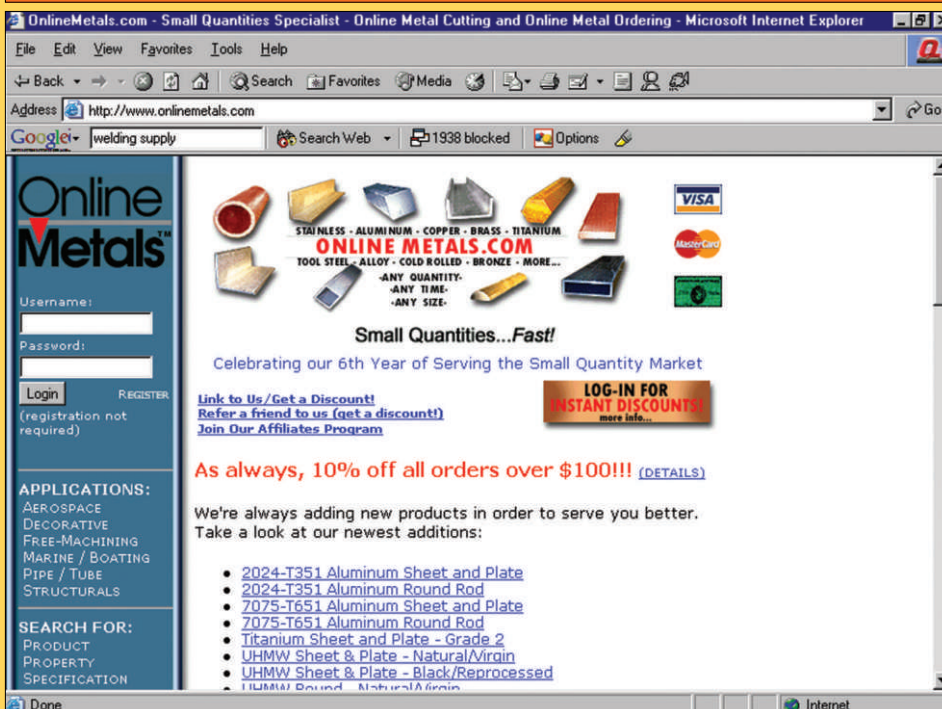
Fasteners (including stainless steel), steel stock, shop tools, ferrous and non-ferrous pipe and fittings, cutting tools and abrasives, hardware (swivels, brackets, etc.), and equipment.

EL-COM

www.elcomhardware.com

Fasteners and hardware, mainly for cabinetry. Also casters, aluminum extrusions (squares, channels, bars),

FIGURE 1. OnlineMetals.com is a source for buying different types of metals — even in small quantities.



plastic laminates, and foam products.

Goodfellow

www.goodfellow.com

Goodfellow supplies metals, polymers, ceramics, and other materials for research, development, and specialist production. Products include sheet, ball, bar, and rod in all common metals, plus exotic metals, such as tungsten and titanium.

High Performance Alloys

www.hpalloy.com

Online retailer of specialty alloys for specialty projects, such as Hastelloy, Inconel, Monel, Nitronic, cobalt based, and commercially pure nickel. Stock includes bar, wire, sheet, plate, and fasteners.

Note that many of these alloys are much tougher than aluminum and even steel. If you plan on working with these metals, be sure you have the proper tools. For example, many desktop machine lathes and mills are not powerful enough for the tougher alloys; you need full-size machinery to do the job right.

Hooper Supply

www.hoopersupply.com

Hooper Supply is an online retailer of welding equipment and supplies,

mostly geared toward the auto and motorcycle enthusiast.

Industrial Metal Supply Co.

www.industrialmetalsupply.com

Metals include: aluminum, brass, cast iron, chromoly, copper, hobbyist "miniature" shapes and extrusions in silicon, bronze, stainless, and steel. Locations in: Phoenix, AZ and Sun Valley, Irvine, and San Diego, CA.

JC Whitney

www.jcwhitney.com

JC Whitney is a well-known and established mail order automotive supply company. Among their tens of thousands of products are welding tools and supplies aimed at the automotive repair business. Products include books, rods, spot welders, and wire-feed welders.

K & S Engineering

www.ksmetals.com

K & S Engineering makes all those metal rods, bars, and other pieces you see in hobby stores across North America. They sell strictly to retailers (including some home improvement centers), though you can find their wares through online sources, as well. The product line consists of steel, aluminum, and brass in bar, tube,

MACHINE FRAMING

Machine framing is aluminum rod that is extruded into various shapes. It's designed to create "construction set frames" for building machinery. With the appropriate connectors and accessories, it's possible to assemble a frame with aluminum profile extrusions that has few — if any — nuts and bolts. Everything is held together with connectors that cinch against the T-slots.

You can use these pieces of aluminum to create strong and light-weight frames for larger robots — no welding not required. With the proper connectors, your robot frames can be re-configurable. There are swivel joints, for example, that allow you to change the shape of the frame by loosening a set screw, moving the joint to a new position, and re-tightening the screw.

A few sources will sell a few pieces

at a time, but most expect a big order and prefer working with industrial clients and factories. Check minimum order requirements and note special shipping charges. Unless the seller will cut the pieces for you, there may be extra freight charges because the extrusions normally come in eight-foot (or longer) lengths.

80/20, Inc.

www.8020.net

Alloy Frame Systems

www.alloyframesystems.com

Bosch Automation Products

www.boschrexroth.com

Frame World

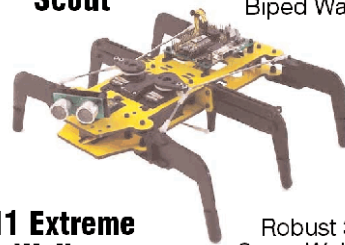
www.frame-world.com

www.lynxmotion.com



Biped Scout

6DOF Biped Walker



H1 Extreme Walker

Robust 3 Servo Walker



H2 Extreme Walker

Performance 12 Servo Walker



Lynx 6 Robotic Arm

Five DOF Arm



4WD2 Rover

Articulating Chassis

We have many more unique robot kits. Our robots feature:

- Precision Laser-Cut Lexan
- Preassembled Electronics
- Custom Aluminum Components
- Injection Molded Components
- Very High Coolness Factor

Toll Free: 866-512-1024

Web: www.lynxmotion.com

Robotics Resources

square, sheet, foil, and shim. Lengths are from 12 inches to 48 inches.

McNichols Company www.mcnichols.com

McNichols sells various forms of unusual extruded metals, including perforated, metal bar grating, wire cloth, expanded metal (even some fiberglass thrown in for good measure). Available in sheets and plates. The product is strong, yet lightweight.

MetalMart.Com www.metalmart.com

Metals (and some plastic) by mail. Walk-in stores, primarily in the Midwest and Great Lakes, as well as Texas and North Carolina.

MetalsDepot www.metalsdepot.com

Metals — rod, sheet, and all the rest. Materials include: steel, aluminum, stainless, brass, copper, bronze, cold finish steel, alloy steel, tool steel, spring steel, cast iron, and titanium.

Metalworking.com www.metalworking.com

Online resources for the recre-

ational/crafts/metalworking community of hobbyists and small businesses.

National Supply Source www.nolansupply.com

National Supply Source sells industrial supplies, tools, and metals. They have a separate 100 page metal shop catalog where you can purchase a variety of types, sizes, and alloys — with no minimums.

They have alloy steel, copper, brass, aluminum, cast iron, and many other types in rod, tube, sheet, and plate form.

Online Metals www.onlinemetals.com

Mail order metal supply: aluminum, stainless, copper, brass, steel. Available in: plate, sheet, rod, tube, etc.

OrderMetals.com www.ordermetal.com

A 26,000 ton inventory of steel and metal. Stock includes aluminum, stainless, copper, and brass, in extruded shapes, plates, sheets, and expanded sheets. They will cut and shape to order.

Sam Schwartz, Inc. www.samschwartzinc.com

Retailer of metals, plastics, and substrates, in aluminum and other metals.

TM Technologies www.tinmantech.com

TM Technologies provides tools and methods for metalworkers, such as those in body shop repair. Products include fairing angle curving dies, silver brazing rod, and fasteners.

Torchmate www.torchmate.com

If you're cutting out shapes in sheet metal, nothing beats the speed and accuracy of a CNC (computer numerically controlled) plasma torch. Torchmate is one of several companies selling both the components and complete plasma torch CNC packages, including cutting software.

Welding Depot weldingdepot.com

Welding kits (TIG, MIG, gas, etc.), consumables, and welding accessories.

WeldingSupply.com www.weldingsupply.com

Mail order sellers of welders (including gas, TIG, MIG, and other types), consumables, and supplies. Gasses can be shipped to limited areas in IL, IN, and WI.

XPress Metals www.midlandxpressmetals.com

Aluminum, brass, copper, steel, stainless steel, and other metals, in tube, bar, pipe, square, sheet, plate, and other shapes. The website lists 1,000 items for online sale; the company warehouses 10,000 items, so be sure to call if you need something special. Local retail stores in Cleveland, OH and Clearwater, FL. **SV**

FIGURE 2. Frame World provides aluminum profiles — useful for constructing robot bodies.



AUTHOR BIO

Gordon McComb is the author of several best sellers about robotics. Visit his website at www.budgetrobotics.com He can also be reached at robots@robotoid.com

THE ASSEMBLY LINE

Leap of Faith

It is said that a journey of 1,000 miles begins with a single step. Certainly, the material presented in the previous two columns has taken us one or more steps into our journey of duplicating — with updated hardware and software — a 1950s robot.

At the same time, the excitement that comes with starting a new project is balanced against the fear of failure. What if it does not work at all? What if smoke comes out of the stepper-motor driver? What if the robot runs around in circles? As with any worthwhile project, you learn from your mistakes. Even experienced engineers make mistakes. A well thought-out design may still contain errors. The real world is different than the paper or simulated world where the design begins.

Do not despair, though. We will solve the problems that come up. The troubleshooting methods will be explained and we will become better designers for having suffered through it. It takes a leap of faith to take the first step of the long journey.

Recall that we have two basic requirements for the design of our new robot (which has been named Uno):

1. As it seeks a light source, Uno must have the ability to move and change direction on a smooth, level surface.

2. Uno must have the ability to change its motion when an obstacle is encountered.

Let us decompose these two

requirements and investigate how Uno will accomplish them. Table 1 matches requirements with the physical components of Uno that will provide them.

Suddenly, Uno has gone from an abstract challenge to something that is beginning to take shape in reality. The process used to make the design decisions will be different for everyone, even with common information and shared goals. Some designers like to think about the design for a long time before making any choices. Others like to talk to a committee of individuals to get their opinions. There may also be merit in just slapping down whatever comes to mind right off the bat and going for it.

The reasoning for Uno's design is as follows: DC motors will do fine on a flat surface. Since switching the polarity of the voltage to a DC motor changes its direction, the DC motor will handle

forward and backward movement. The weight of Uno will, hopefully, be enough of a load to prevent Uno's speed from becoming too fast.

Since Uno will not be moving very fast, it will not be necessary for it to turn very quickly, either. Using a stepper motor to control the position of the front wheel will provide a quick enough mechanism for changing direction as Uno rolls forward or backward.

A photoresistor will be used to sense the intensity of an ordinary light bulb. This keeps everything simple and does not rule out a future upgrade to a phototransistor or other type of optical sensor. An intensity circuit is required for the photoresistor to create the desired voltage versus intensity range.

An electromechanical tilt switch will be used to sense a collision. The sensitivity of the switch may be related

Requirement	Uno Component
Ability to move and change direction	One DC motor to operate a pair of rear wheels. One stepper motor to control the direction of a front wheel that swivels.
Move on a smooth, level surface	No need for brakes.
Seek a light source	A photoresistor for sensing brightness. An analog-to-digital converter will digitize the intensity level.
Ability to change its motion	An intelligent process is required here. This will be provided through the software of a microcontroller.
React when encountering an obstacle	Miniature tilt switch used to detect the bump of a collision with an obstacle.

Table 1. All of Uno's design requirements are met through the physical components listed here. Each physical component was chosen for a specific reason.

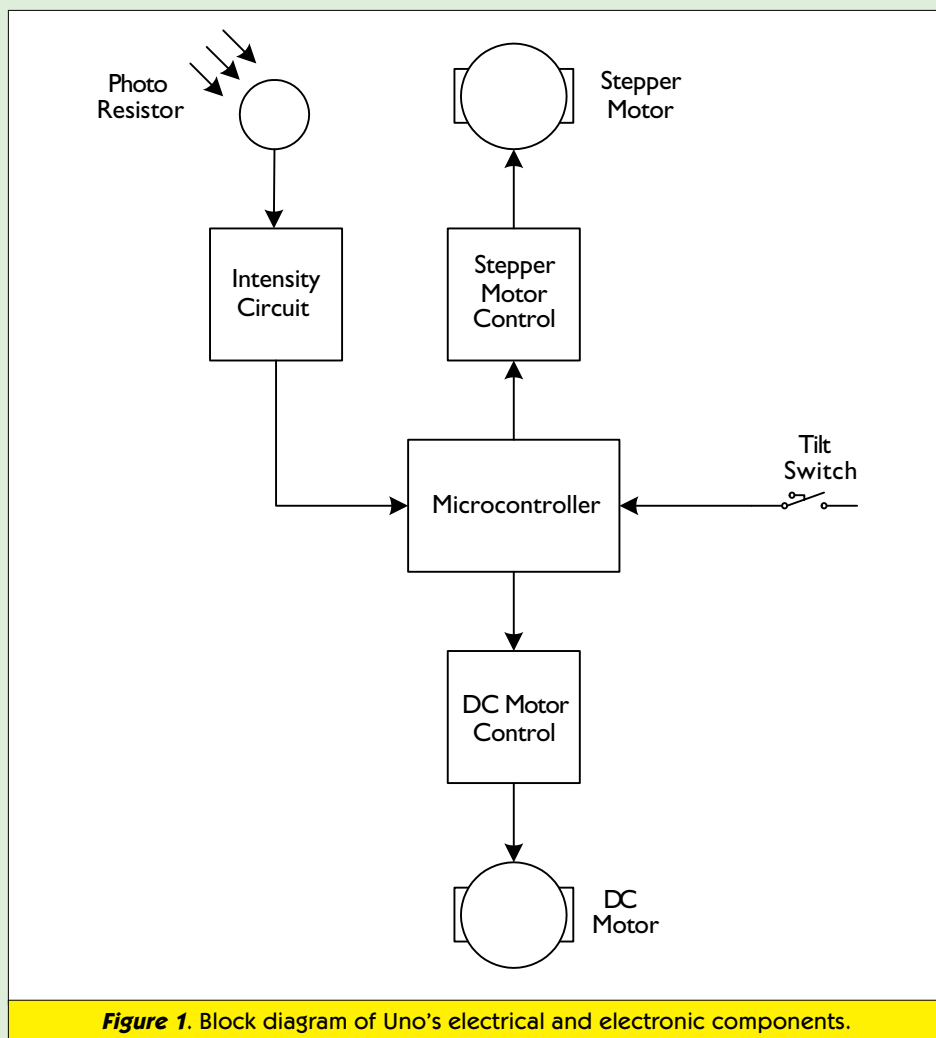


Figure 1. Block diagram of Uno's electrical and electronic components.

possibly the addition of one or more additional sensors.

At the center of everything will be a microcontroller. This will give Uno its intelligence and personality. Many microcontrollers contain internal multi-channel A/D converters. One input channel will be needed for the output from the intensity circuit. Digital outputs will be necessary for the motor control circuits. The microcontroller will control the stepper motor using software and the appropriate output patterns, instead of using a dedicated stepper-motor controller chip. This keeps the cost down and allows more control over the motor. Plus, it is cooler to do everything ourselves.

Figure 1 shows Uno's electrical and electronic system in block diagram format. The power supply is not shown, but is required and must be contained within Uno's chassis — along with all the other components. One or more batteries will be necessary. In fact, separate power sources may be used — one for the motors and a second for the microcontroller and other electronics. This may help isolate the high-current drain of the motors from the low current electronics.

Figure 2 shows the top view floor plan of Uno's chassis. Just the shape and general placement of the components are indicated; no actual dimensions are known at this time. When the parts are

to where it is located within Uno's chassis and its orientation. It is expected

ed that sensing a collision correctly will require some troubleshooting and

are indicated; no actual dimensions are known at this time. When the parts are



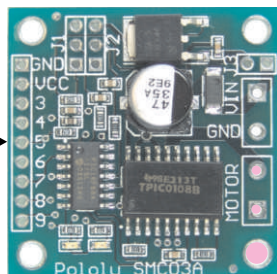
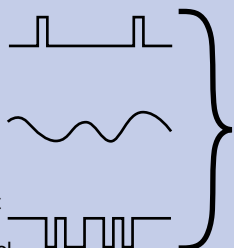
Motor Control Choices from Pololu

1. Choose your protocol.

RC servo protocol lets you connect to an RC receiver or serial servo controller.

Analog protocol is simple for quick tests and demonstrations.

Serial protocol is great for microcontroller- or computer-based control.



shown actual size

2. Choose your motor.

With an operating range of 6 volts to 18 volts and up to 3 A of current, you'll have many motor options.



3. Choose your feedback mode.

Position feedback mode allows you to use a potentiometer or other analog voltage source to accurately move to exact positions.

Speed feedback mode allows for tachometer-based control of your motor's speed.



Visit www.pololu.com or call 1-877-7-POLOLU for more innovative motion control solutions.



purchased, the overall dimensions will be fine-tuned. Room for expansion and future upgrades is built into the floorplan. For example, we may need to add more tilt sensors. There is room on both sides and in the back for additional hardware.

Compare the computer-drawn floorplan of Figure 2 with the original hand-drawn sketch shown in Figure 3. A sketch is a sketch; it does not have to be perfect and nothing is etched in stone. In fact, notice that there have already been changes made to the floor plan in terms of component placement and dimensions. Remember that the design will evolve; it is a dynamic thing. Do not fall in love with your first idea, design, or sketch, as this may blind you to improvements or other aspects of the design.

Why struggle with all the headaches of a new design, the cost of the parts, and the labor of assembly, testing, and troubleshooting? It is much easier to buy a pre-designed

robot kit for much less money. Putting together a robot from a kit may be more worthwhile — especially for a beginner — but there is a larger measure of pride in designing and building the robot from scratch with off-the-shelf (or through-the-catalog) parts. It is typically more expensive to do it on

your own, but it is also more rewarding and you get the exact robot you want when you are finished.

Next time, we will examine the actual components purchased for Uno's construction and what changes — if any — must be made to the design. **SV**

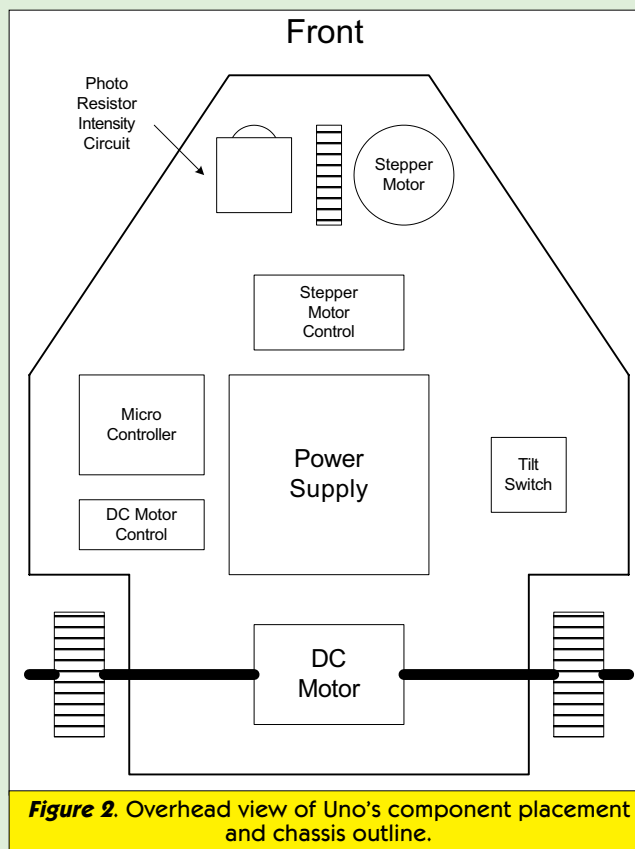


Figure 2. Overhead view of Uno's component placement and chassis outline.



Figure 3. Original hand-drawn sketch of Uno's chassis floor plan.

ABOUT THE AUTHOR

James Antonakos is a Professor in the Departments of Electrical Engineering Technology and Computer Studies at Broome Community College. You may visit his website at www.sunybroome.edu/~antonakos_j

Robotic CrustCrawler Design & Development

Specifications:

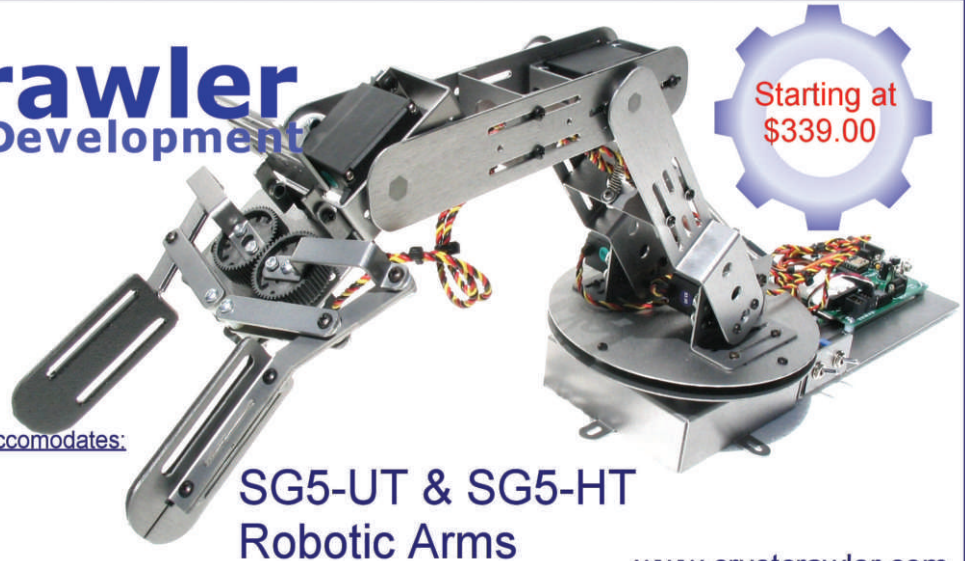
- ↪ Arm height: 17.75" (45.1cm)
- ↪ Base rotation: 180 degrees
- ↪ High resolution 60 tooth geartrain
- ↪ Lifting capability up to 14.23 oz.!

Electronics:

- ↪ Parallax BOE/BS2p24 and PSC
- ↪ Add your own

Sensor engineered gripper design accomodates:

- ↪ Pressure sensors
- ↪ CCD cameras
- ↪ Proximity sensors
- ↪ Infrared detectors



Starting at
\$339.00

**SG5-UT & SG5-HT
Robotic Arms**

www.crustcrawler.com



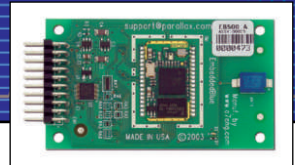
BRAIN

RADIO DATA LINKS — TRANSCEIVERS

SUPPLIER	Model	Networking	Communication Type	Frequency	Range, outdoor line of site	Power
ABACOM Technologies www.abacom-tech.com	WIZ-SML-IA-5V	Point to Point	RS232	914.5 MHz	150 m	10 mW
Aerocomm www.aerocomm.com	AC4490-200	Point to Point	RS232/422/485	900 MHz	6,400 m	200 mW
	AC5124-200	Point to Point	RS232/422/485	2.4 GHz	10,000 m	200 mW
Laipac Tech www.laipac.com	RD900DV	None	FIFO	900 MHz	350 m	2 mW
	RF2400DV	None	FIFO	2.4 GHz	350 m	3 mW
	TRF-2.4G	None	FIFO	2.4 GHz	150 m	3 mW
Lemos International www.lemosint.com	Promi-SD	Bluetooth	RS232	2.4 GHz	1,200 m	63 mW
Linx Technologies www.linxtechnologies.com	TR-916-SC-PA	Point to Point	RS232/485	916 MHz	200 m	3 mW
Maxstream www.maxstream.net	9XCite	Peer to Peer, Point to Point, Point to Multipoint	RS232/422/485	900 MHz	300 m	4 mW
	9XStream	Peer to Peer, Point to Point, Point to Multipoint, Repeater	RS232/422/485	900 MHz	11,000 m	140 mW
	9XTend	Peer to Peer, Point to Point, Point to Multipoint, Repeater	RS232/422/485	900 MHz	22,000 m	1 W-1 mW
	24XStream	Peer to Peer, Point to Point, Point to Multipoint, Repeater	RS232/422/485	2.4 GHz	5,000 m	50 mW
Parallax, Inc. www.parallax.com	433 MHz Transceiver	Point to Point, Point to Multipoint	RS232	433 MHz	75 m	1 mW
	EmbeddedBlue	Bluetooth	RS232	2.4 GHz	100 m	2.5 mW
	SureLink900	Point to Point, Point to Multipoint	RS232	900 MHz	300 m	130 mW
Radiometrix LTD www.radiometrix.com	BiM2-433-160	None	FIFO	433 MHz	200 m	10 mW
	SPM2-433	Point to Point, Point to Multipoint	RS232	433 MHz	200 m	10 mW
VANTEC www.vantec.com	KH932	None	A to D	75 MHz	1,500 m	250 mW

MATRIX

by Pete Miles



Upcoming topics include SBCs and H-bridges, sensors, kits, shop tools, and actuators. If you're a manufacturer of one of these items, please send your product information to: BrainMatrix@servomagazine.com Disclaimer: Pete Miles and the publishers strive to present the most accurate data possible in this comparison chart. Neither is responsible for errors or omissions. In the spirit of this information reference, we encourage readers to check with manufacturers for the latest product specs and pricing before proceeding with a design. In addition, readers should not interpret the printing order as any form of preference; products may be listed randomly or alphabetically by either company or product name.

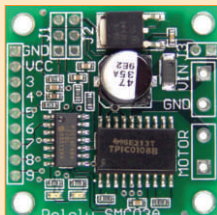
Antenna	Rate, bits per second	Connector	Number of Channels	Data Encryption	Size	Supply Power	List Price
Internal Surface Mount	9,600 to 115.2k	2 x 5 pin	1	No	1.75 x 3.54 x 0.4	5 VDC	\$145.00
MMCX	up to 115.2k	20 pin	32	Yes, 8 bit	1.65 x 1.90 x 0.2	3.5-5 VDC	\$64.00
MMCX	up to 115.2k	40 pin	77	Yes, 8 bit	1.65 x 2.65 x 0.2	5 VDC	\$110.00
External	300 to 100k	13	16	No	1.65 x 1.97 x 0.4	3.6 VDC	\$40.00
External	up to 100k	13	8	No	1.57 x 2.00 x 0.4	5 VDC	\$52.00
Internal Surface Mount	up to 1,000k	2 x 5 pin	125	No	0.81 x 1.20 x 0.1	1.9 to 3.6 VDC	\$19.00
RP-SMA	1,200 to 115.2k	9 pin	1	No	2.36 x 1.00 x 0.6	5 VDC	\$159.00
RP-SMA	up to 33.6k	Dual 10 pin	1	No	1.10 x 1.50 x 0.4	2.7 to 13 VDC	\$48.00
3" Integrated Wire or RP-SMA connector	1,200 to 57.6k	11 pin & 4 pin	7	No	1.60 x 2.83 x 0.35	2.85 to 5.5 VDC	\$47.00
3" Integrated Wire, RP-SMA, or MMCX connector options	1,200 to 57.6k	11 pin & 4 pin	7	No	1.60 x 2.83 x 0.35	5 VDC	\$138.00
RP-SMA or MMCX connector options	1,200 to 230.4k	20 pin	10	Yes, 256 bit AES	1.44 x 2.38 x 0.2	2.8 to 5.5 VDC	\$179.00
3" Integrated Wire, RP-SMA, or MMCX connector options	1,200 to 57.6k	11 pin & 4 pin	7	No	1.60 x 2.83 x 0.35	5 VDC	\$95.00
Internal Surface Mount	9,600	17 pin	16	No	1.75 x 3.25 x 0.5	5 VDC	\$119.00
Internal Surface Mount	9,600 to 230.4k	20 pin	2^48	No	2.70 x 1.60 x 0.2	5 to 12 VDC	\$99.00
Internal Surface Mount	1,200 to 115k	15 pin	16	Yes, 128 bit	1.73 x 2.36 x 0.2	3.5-12 VDC	\$59.95
External	up to 160k	Dual 9 pin	1	No	1.30 x 0.90 x 0.2	3 to 5 VDC	\$69.00
External	1,200 to 14.4k	Dual 11 pin	15	No	0.90 x 1.50 x 0.3	3 to 5 VDC	\$90.00
External Included	7,000	30 pin & 18 pin	20	Yes, PCM	4.25 x 1.0	4.8 VDC, 9.8 VDC	\$812.53

New Products

CONTROLLERS & PROCESSORS

Amp DC Motor Controller With Closed-Loop Control

Pololu introduces its new 3 amp motor controller with multiple interface and feedback options for simplifying servo control of commonly available DC motors. The module features three independent interfaces: a serial protocol for microcontroller-based applications, a pulse-width interface for connection to hobby radio control equipment or serial servo controllers, and an analog voltage interface for simple tests and demonstrations. Two feedback alternatives allow for closed-loop control of position or speed.



The new motor controller distinguishes itself from other devices in its class by offering a complete feedback-based solution for applications requiring bi-directional, closed-loop control. The user can select either an analog voltage feedback or a digital encoder feedback (quadrature encoding is not supported). With the two feedback alternatives, various simple devices such as potentiometers can be used as sensors to achieve position or speed control.

In a typical application, a user first sets up the motor controller's parameters based on the physical properties of the mechanical system that is being driven. A feedback potentiometer is coupled to the mechanism output and the user can then send position commands to the motor controller, which automatically drives the motor to reach the position. Alternatively, the mechanism and sensor can be arranged to provide speed feedback, in which case the motor controller maintains given speeds despite fluctuations in friction or supply voltage.

The motor controller measures 1.4" x 1.4" and has an

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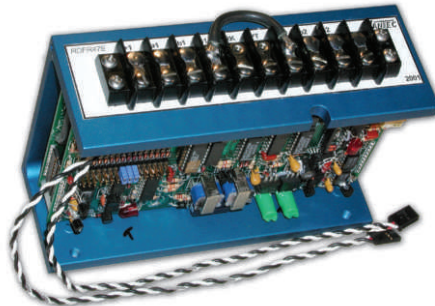
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operating voltage of 6 volts to 18 volts, making the device well-suited for small robots and other projects using toy motors and rechargeable 7.2 V or 9.6 V battery packs. The motor controller serial protocol is compatible with other Pololu motion control devices, allowing multiple units to be connected to a single serial line to control a mixture of motors sizes and hobby RC servos.

The unit price for the motor controller is \$49.00, with free shipping in the US.

For further information, please contact:

Pololu Corporation

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Las Vegas, NV 89119
Tel: 877 • 7 • POLOLU or 702 • 262 • 6648
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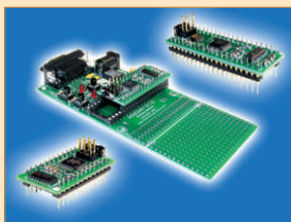
Circle #28 on the Reader Service Card.

High Performance MCU Modules

Technological Arts has launched a trio of MCU modules based on the Freescale Semiconductor 9S12C microcontroller family. Fashioned in a format that is pin-compatible with most other popular Dual Inline Package (DIP) microcontroller products on the market today, these modules — dubbed NanoCore12 — bring significantly enhanced performance and value to the user. As a major bonus, the modules can be operated at either 3 or 5 volts.

Designed to offer engineers, OEMs, and educators a compact and economical solution, the NanoCore12 family will find its way into a myriad of applications. Well-suited to new product development, the modules are equally capable of retrofitting existing systems for the purpose of upgrades and enhancements. Furthermore, those who have already invested significantly in support hardware for existing DIP modules will be relieved to learn that their investment is not lost. In most cases, they only need to de-populate the less capable DIP module and replace it with the appropriate NanoCore12 counterpart.

The 9S12C32 MCU features a high speed, low voltage core, 2K RAM, and 32K sector-erasable Flash, along with an impressive array of hardware subsystems. These subsystems include CAN, enhanced SCI, SPI, 10-bit



eight-channel analog-to-digital converter subsystem, four PWM channels, triple four-channel, 16-bit enhanced capture timer subsystem, and much more. The full complement of subsystems provided — including a powerful single-wire Background Debug Module (BDM) — make this chip ideal for use in the evaluation and development of all "C"-series derivatives of the 9S12 family. A phase-locked loop enables dynamic operating speeds up to 48 MHz, offering the potential for intelligent power management through software.

Combining all the essential MCU support circuitry with a small footprint monitor/loader program in Flash, NanoCore12 modules are supplied ready-to-use with an onboard 5 volt regulator for power and an onboard RS232-C transceiver for communication. The user only needs to add application-specific interface hardware and software to implement a given design. The NanoCore12 family is supported by a complete range of accessories and is offered in 24-, 32-, and 40-pin DIP footprints; single-piece pricing for NanoCore12 modules is \$45.00 (NC12), \$59.00 (NC12DX), and \$79.00 (NC12MAX), respectively. OEM pricing starts at \$23.00 (1,000 units). Complete details can be found at www.technologicalarts.com/myfiles/nc12.html

For further information, please contact:

Technological Arts

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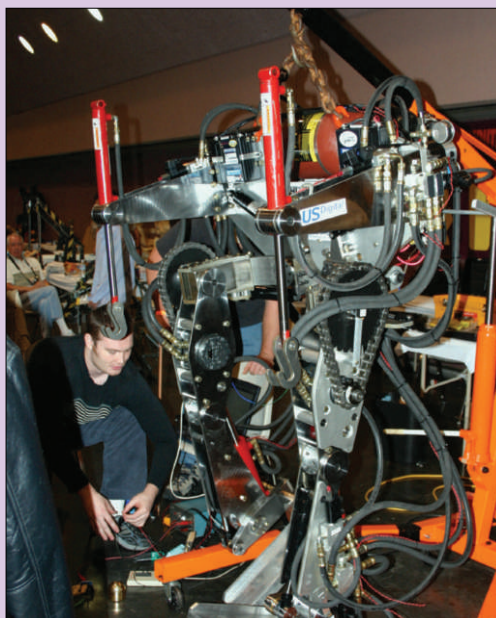
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CHECK OUT TETSUJIN!



Jascha Little stands in Mechanicus, which couldn't shake its software control problems in time to compete. It was the most ambitious — and the heaviest — entry at the event.



Weighing in at over 1,100 lbs, Mechanicus was a 14 DOF hydraulic walking suit. Jascha and his father Scott worked desperately on the control firmware but, in the end, couldn't pull it off.



Photo courtesy of Steve Judd

Competitor Bryan Hood suits up to compete in his chromolly framed, pneumatically powered exosuit. Max lift: 160 lbs, max score: 15.2 points.

Donning the Technotrousers, Dan Rupert performs his maximum lift of the event — 650 lbs (after falling on the first two attempts) and earning a score of 33.5 points. Volunteer Stephen Felk measures the height while teammate Donald Hutson cheers Dan on!



Chuck Pitzer puts his back into it, giving his exosuit a hand with the heaviest lift of the event — 1,140 lbs. In the background, his brother and teammate Bob nods approvingly. Because of the time factor in the scoring formula, their best lift was just 600 lbs, earning them a score of 68.1 points.



Tetsujin 2004 was a huge success at RoboNexus with standing room only crowds of nearly 500 and dozens of TV crews and photographers documenting the amazing work of our competitors. Here are few selected pictures from our editors; you can look forward to ongoing coverage in upcoming issues of SERVO.



Everything that goes up, must come down. A slight sequencing error in the hydraulic valves caused Team Raptor's Pinch Point to bounce and fall over during descent, with the competition weights landing in the sand pads. Chuck and Bob discuss the best way to recover their machine — anyone got AAA?



Photo courtesy of Steve Judd

Media coverage of the event was huge. Here, Chuck Pitzer from Team Raptor explains his exosuit, Pinch Point, to a film crew from Discovery Channel.

We would like to extend our thanks, once again, to the great sponsors that stood behind Tetsujin!

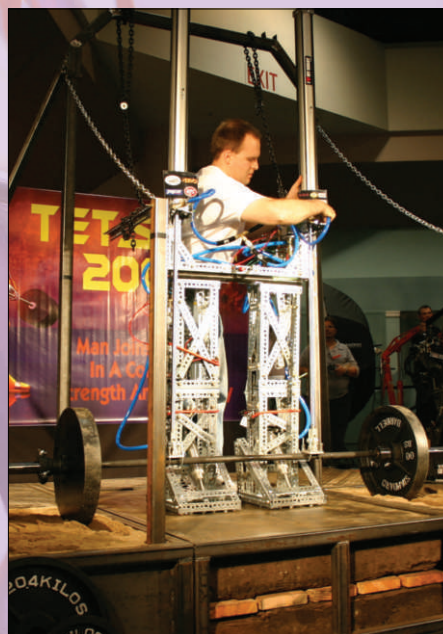


The Technotrousers stand ready, awaiting an operator. True to the spirit of Tetsujin, Dan Rupert and Don Engh's entry was a genuine strength augmentation suit.



Photo courtesy of Steve Judd

Alex Sulkowski preps his exosuit for a 240 lb lift. His frame was made from light structural angle, but sported the longest pneumatic cylinders anyone had ever seen! Max lift: 450 lbs, max score: 147.9 points.



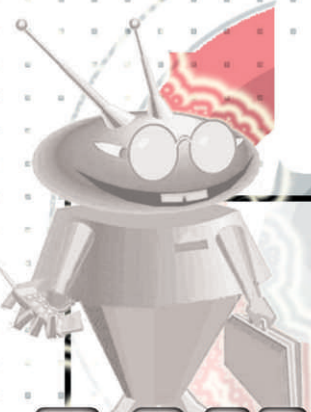
Don Engh snatches 450 lbs in the Technotrousers. This exosuit used electric motors to compress gas shocks in the feet when reaching down for the bar, then recovering that energy to aid in the lift of the weights. Clever!



OFFICIAL RESULTS

First Place: Alex Sulkowski, Team Xela, 147.9 points

Second Place: Chuck Pitzer, Team Raptor, 68.1 points **Third Place:** Dan Rupert, Team Techotrousers, 33.5 points



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ASK MR. ROBOTO

by
Pete Miles

Q Are there any low cost tools for bending aluminum into boxes? I have gotten pretty good at using a hammer and a vise to bend most of my parts, but I have a lot of trouble trying to make bends that are smaller than the jaws on my vise.

— **Carl Statton**
 via Internet

A What you are looking for is typically called a pan and box brake. The pan and box terms come from the fact that they are commonly used to make boxes and pans. I have found that the vise brakes from Grizzly (www.grizzly.com) work great. They attach directly onto the jaws of the vise with a pair of high strength magnets so that they are easy to put on and remove (Figure 1). To bend the part, just put it between the male and female dies and align the front edge of the male die with the bend line on your part and then crank the vise closed.

Adjusting how much the vise is closed can produce any bend angle between 0 to 90 degrees. The male part of the vise brake has three segments so that its overall width can be adjusted to prevent damaging the previously bent sides of a

box/pan. Because of the low cost of these vise brakes, several of them can be purchased and the die segments can be cut down into smaller widths for a large variety of custom bending work (Figure 2).

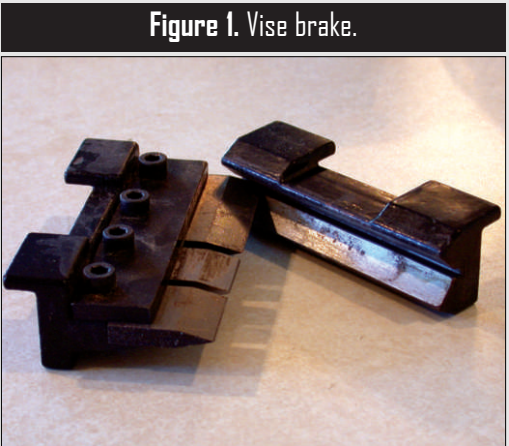
Another option that is a little more expensive would be to use a bench top pan and box brake. The 12 inch brake shown in Figure 3 — also from Grizzly — works by clamping one side of the part down and bending the other side up. Like with the vise brake, the clamping segments on this brake can be adjusted to change the widths of the die so that different box widths can be bent. This tool has an advantage in that it can bend sheets up to 12 inches wide and angles up to 135 degrees (Figure 4).

Table 1 shows a list of some other relatively low cost bending brakes from Grizzly that can be used for making boxes.

Q I got a Sumobot Mini Sumo Kit for my birthday and I had a lot of fun building it and playing with it. We had a contest at school last week and my robot could not push any of the other robots out of the ring. Most of the other kids had Sumobots, too, but I couldn't get mine to push them out of the

Name	Part No.	Max. Bending Width	Max. Recommended Gauge, Steel	Other Forming Features
Vise brake	H3243	4"	16	None
Vise brake	H3244	5"	16	None
Vise brake	H3245	6"	16	None
Mini shear brake	G9950	7-1/2"	22	Shear
12" pan and box brake	G0556	12"	20	None
24" pan and box brake	G0557	24"	20	None
12" sheet metal machine	G6089	12"	22	Shear & slip roller
12" sheet metal machine	G4011	30"	22	Shear & slip roller

Table 1



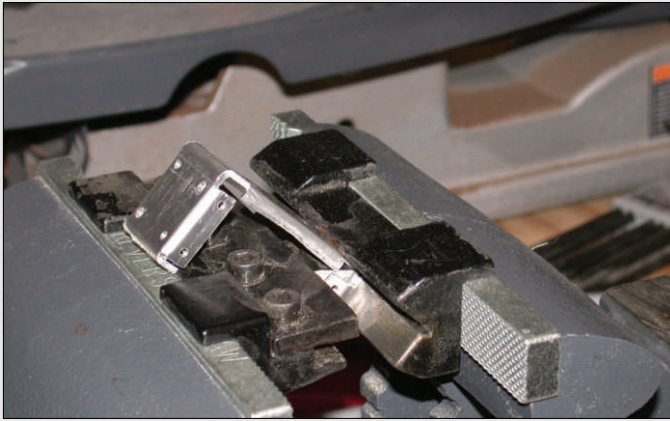


Figure 2. Vise brake bending an aluminum bracket.



Figure 3. Grizzly 12" pan and box brake.

ring. Can I use bigger motors to win?

— **Ed Tacking**
via Internet

A.The Sumobot Mini Sumo Kit is a great kit for learning how to make small, programmable robots and they make a fine mini sumo robot. Changing the motors will not help you in mini sumo. The motors that come with the kit have more power than you need to push your opponent out of the ring. What you need to do is increase your traction.

The very first thing to do is make sure that your robot is at maximum weight for the contest. In mini sumo, the maximum weight is 500 grams and the Sumobot kit — with batteries — only weighs 360 grams. The easiest way to increase the weight of the robot is to add lead weights to it.

Your local hobby store should have some weights and double-sided tape (found in the model airplane section) or you can get some weights from the fishing section of your local sporting goods store. Place your robot on a scale and start adding weight until your robot gets to 500 grams. By doing this, you will immediately see greater pushing performance from your robot.

The second thing you need to do is increase the traction on your wheels. Whatever you do, make sure your wheels are clean before each match. Any form of dirt/dust on the wheels causes them to lose traction, so clean them before each match.

Now, here is my personal trick that I use in all of my sumo robots: I apply a thin layer of silicone on the surface of the tires (Figure 5). The rubberband that comes with the mini sumo wheel gives it a lot more traction than its core plastic wheel, but silicone on the wheel gives it a lot more traction than the rubberband. You will want to use RTV (Room Temperature Vulcanizing) silicone that can be found at most automotive and hardware stores. A thin coating on the rubberband is all you need. A wooden applicator — such as a popsicle stick — works well at applying it to the wheel. It doesn't have to be perfectly smooth. Allow it to dry for at least 24 hours before a contest.

Doing these two things will significantly improve the fighting performance of your mini sumo, after which you can

start using software to outsmart your opponents. For even more information on increasing wheel traction for sumo robots, read my article in the December, 2003 issue of *SERVO Magazine*.



I don't have a mill; can I put a milling bit in a drill press and go to town?

— **Will M.**
Indianapolis, IN

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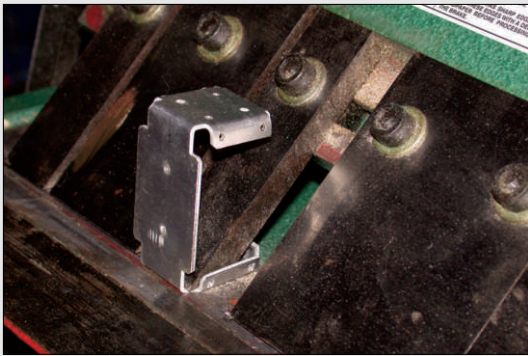


Figure 4. Aluminum bracket being bent with the Grizzly 12" pan and box brake.



Figure 5. Silicone-coated yellow mini sumo wheel with a blue RTV silicone.

A. Well, yes and no. First off, drill presses are not designed to handle the high lateral loads that are developed during the milling process. This is because the spindle bearings are not designed to handle the high side loading, but rather more of an axial (drilling) loading. The entire structure of the drill press is not rigid enough to hold the workpiece and milling bit rigid without allowing significant vibrations. Finally, the collets that are used to hold the drill chuck in the spindle are not held securely in place

by a draw bar. Now, with that said, there are some things that can be done. Soft metals (aluminum and brass), plastics, and woods can be milled using a drill press. You will need to use a compound slide for moving the workpiece under the milling bit. You will need clamping tools to clamp the workpiece to the compound slide and the bottom of the compound slide must be

clamped to the drill press table. Then, you should replace the drill chuck (the drill chuck could be used to hold the end mill, but is not recommended) with a standard end mill collet. You will need to make sure that you use the same shank design that the drill chuck used — typically either an MT#2 or MT#3. After doing all this, your drill press can do some milling operations. I wouldn't use any end mill greater than 3/8" in diameter. When milling, take very light cuts — mainly for safety reasons because you are using a drill press in an application that it is not designed for. This will void any warranty. Many people have done this and have been happy with their results, but one thing is for sure — the life of your drill press will be greatly reduced and the chances of breaking the drill or injuring yourself are much higher.

Q. I have been programming BASIC Stamps for a couple of years now and I would like to move onto something that is much faster and has more programming capabilities. For a while now, I have been thinking about learning how to program in assembly, but it seems like a

Listing 1. SX/B Basic program for blinking an LED.

```

=====
\ Device Settings
=====
DEVICE          SX28, OSC4MHZ, TURBO, STACKX, OPTIONX
FREQ            4_000_000

High ra.0
Main:
  Toggle ra.0
  pause 500
  goto Main
  
```



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backward language. Do you have any recommendations?

— Chris Sparks
San Diego, CA

A First off, there really isn't one language that is better than another. It really comes down to what you are comfortable with using. Assembly language programming does seem strange when you are used to programming in Basic, but — once you get used to it — it becomes as easy to program as Basic.

With assembly, you have full access to all of the microcontroller's features, which are more difficult to implement when using a higher language, such as Basic; these features include interrupts, watch dog timers, comparitors, error traps, and what to do upon resets — just to name a few.

Since you are already familiar with BASIC Stamps, I would recommend that you take a look at the SX/B Basic Compiler that Parallax (www.parallax.com) is now distributing FREE for programming the SX chips. As you will recall, the SX microcontrollers are the core microcontrollers for 75% of Parallax's Stamp products. With this compiler, you can directly program your own SX chips with the same programs that you already have.

The SX/B uses essentially the same PBasic that the Stamps already use, so this helps to simplify the learning curve for how to program in assembly. What I really like about this program is that its listing file will show you the exact assembly language that is created for each line of code that is used in your PBasic program. This helps teach you how the various assembly language commands are put together and used to accomplish a specific task. Also, the assembly that is generated by the SX/B compiler can be edited and re-compiled to change how the program works or it can be copied and pasted into other programs.

For example, Listing 1 shows a simple Stamp2 program to blink an LED once a second. One of the obvious differences between this program and regular PBasic is that — instead of using the directive {\$STAMP BS2} at the start of the programs — you have the DEVICE line in the SX/B program. In essence, they are the same thing. It is telling the compiler what microcontroller is being used. The FREQ line tells the microcontroller how fast to operate at — 4 MHz, in this case. The SX microcontrollers can run up to 75 MHz! The ra.0 is the actual I/O pin on the microcontroller, so — instead of using High 0 to turn on Pin 0 — the exact I/O pin is addressed.

Listing 2 shows the compiled version of the same LED blinking program. The *Assembly Language Programming Manual* will explain how each of these commands works, but this listing does show you all of the behind-the-scenes activities that occur for some relatively simple PBasic commands. The PBasic commands are shown in the comments and all the assembly language commands below it are needed to

instruct the microcontroller to execute the PBasic command.

This may seem confusing at first, but the downloadable manuals from the Parallax website (www.parallax.com) provide step-by-step instructions for learning how to understand, program, and use each of the assembly language functions. In my opinion, they are probably the best written documentation for learning how to program in assembly language. The SX/B is a good first step toward learning assembly. This knowledge leads to directly programming in assembly. **SV**

Listing 2. Compiled version of the same LED blinking program.

```
; *** COMPILED WITH SX/B VERSION 0.948 ***
;=====
;' Device Settings
;=====
DEVICE                SX28, OSC4MHZ, TURBO, STACKX, OPTIONX

; DEFINE SYSTEM VARIABLES
__PARAM1              EQU    $08
__PARAM2              EQU    $09
__PARAM3              EQU    $0A
__PARAM4              EQU    $0B
__TRISA               EQU    $F9
__TRISB               EQU    $FA
__TRISC               EQU    $FB
__INTPARAMFSR         EQU    $FC
__REMAINDER           EQU    $08

; Define ShiftIn & ShiftOut Constants
LSBFIRST              EQU    0
MSBFIRST              EQU    1
MSBPRE                EQU    0
LSBPRE                EQU    1
MSBPOST               EQU    2
LSBPOST               EQU    3

FREQ 4_000_000                ; FREQ 4_000_000

MOV FSR,#__TRISA                ; High ra.0
CLRB IND.0
MODE $0F
MOV !RA,IND
BANK $00
SETB ra.0

Main:                            ; Main:

MOV FSR,#__TRISA                ; Toggle ra.0
CLRB IND.0
MODE $0F
MOV !RA,IND
BANK $00
XOR ra,#%00000001

MOV __PARAM1,#2                ; pause 500
MOV __PARAM2,#244
MOV __PARAM3,#4
MOV __PARAM4,#231
DJNZ __PARAM4,$
DJNZ __PARAM3,$-2
DJNZ __PARAM2,$-8
DJNZ __PARAM1,$-10

JMP Main                        ; goto Main
```


An **INEXPENSIVE** and **FUN** RS232 Terminal

— by L. Paul Verhage —

Are you looking for a convenient and flexible means of communicating with microcontrollers in the field? Then you may have shared my experience. Several of my microcontroller projects require communications with the outside world. In the past, I've tried using the standard LCD screen and buttons. This is fine for a few simple options, but — when the options become more complex — the menuing system required by the LCD and buttons becomes less convenient.

The BASIC Stamp has a SEROUT and SERIN command capable of displaying a lot of data and using any typed text as input. So, I began connecting my projects to a PC or laptop running a terminal program, like ProComm or HyperTerminal. This worked well when my projects used a single microcontroller and ran at home. Once I created multiple microcontroller applications that needed to be mobile, I ran into the problem (primarily the cost) of requiring multiple PCs or laptops. I looked into using dumb RS232 terminals retired from a mainframe; while they're cheap, they're also big and bulky. Their size and power requirements make them decidedly unfriendly. What I really needed was a small and inexpensive RS232 terminal that I could carry

in my pocket. I asked around

in my pocket. I asked around

Email forums for a possible solution, but I could never find one.

At an amateur radio club meeting several years ago, I was introduced to the Cybiko. It is a child's PDA that's about the size of my first calculator (purchased in 1976). The Cybiko has a standard keyboard and an LCD screen capable of displaying graphics. It also has a serial port, built-in radio, communication software, small speaker, and vibrator motor for silent notification. The Cybiko comes with a serial cable and a wall wart for recharging its two NiMH cells. It also has a stylus for pressing its small buttons. It comes with programs loaded in it — like games, a calculator, and an address book. The Cybiko has a large following and its fans are continually developing new applications for it. You can download these for free over the Internet. To find new games, go to: www.cybiko.com/ Go to <http://cybiko.com/devsarea/> to find the development software. To get the VT-100 terminal program, go to: www.devrs.com/cybiko/

It took awhile before a possible Cybiko solution to my RS232 terminal needs dawned on me. I suspected there was a dumb terminal program for the Cybiko and, after searching the Cybiko Developers website, I discovered just the program. In the rest of this article, I'll introduce you to the Cybiko Classic — Jeff Frohwein's VT-100 emulator (version 1.2) program — and show how to make a communication cable and back-up power supply.

With these, you can make an incredibly inexpensive RS232 terminal for communicating with your microcontroller projects, including robots.

Best of all, the software is free and you can get the Cybiko Classic for as little as \$10.00! If you feel comfortable writing C programs for the Cybiko Operating system (CyOS), then you can create or modify software to include the radio feature of the Cybiko.

How do two \$10.00 radios with full keyboards and displays sound as a means of communicating with your robot? For this article, I would like to thank the two Bills of the Voice of Idaho Radio Club for



introducing me to the Cybiko and how to program it.

Here are the steps for turning a Cybiko Classic into an inexpensive RS232 terminal:

- Purchase a Cybiko Classic
- Download and install two free programs on your PC and two Cybiko applications
- Update the System Pack in your Cybiko (if needed) and erase old programs (if needed)
- Load the files VTterm.app and CommPort.dl into the Cybiko
- Configure the VTterm application
- Build a serial cable
- Make a back-up power supply
- Make a sophisticated reset device
- Program your microcontroller application to use RS232 communications
- Have fun communicating with your microcontroller project with a cheap and portable RS232 terminal

Purchasing the Cybiko

This step is easy. Go to **www.amazon.com** and search for Cybiko Classic. Be sure to get the Cybiko Classic and not the Cybiko Extreme. The Classic uses a serial port (RS232), while the Extreme uses a USB port. Amazon led me to Toys R Us for my Cybikos. I only paid \$10.00 for either a blue or purple one. For some reason, the yellow one was more expensive. They're all identical, though; only the color of the plastic body is different.

Getting Software

There are two programs you need to download from the Internet: CyberLoad and SDK. CyberLoad lets you install or remove games and update the OS of the Cybiko. CyberLoad is available at the Cybiko website, **www.cybiko.com**. Download and install CyberLoad on your PC. The installation process associates the APP file type to the Cybiko. I initially found that the APP file type was associated with FoxPro on my PC, which may cause havoc for the SDK.

SDK is a development system that lets you create applications and upload them into the Cybiko. SDK is also available at the Cybiko website. Download and install the SDK system onto your PC.

The last software to download is the VTterm.app and CommPort.dl files. VTterm is the VT-100 emulator program and CommPort is a support program. Download these two programs from **www.devs.com/Cybiko** and save them on your PC. Don't forget where you put them.

Checking the System Pack

Now, determine what level of system pack came with your Cybiko. Start the Cybiko by pressing the ESC

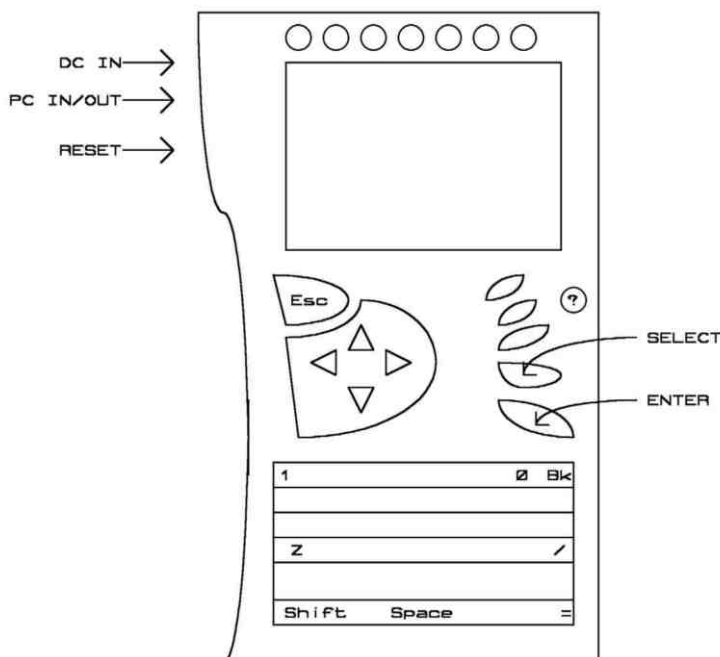


Figure 1: Yes, it looks a bit melted, but that's simply the "hip styling" of this unit. The serial cable plugs in the left of the unit, while the stylus is stored at the top.

button on the top left of the keypad. If the batteries are dead and you don't want to wait until they have been recharged, you can run the Cybiko off its wall adapter. It takes a few moments for the Cybiko to boot up.

As it boots up, look at the bottom of the LCD. There, you'll find listed the CyOS version. The version will be something like 1.3.57. The last two digits — 57 in this case — are the System Pack.

Figure 2: Here's the layout of the Cybiko. Notice the location of the Cybiko buttons that you'll use and the location of the jacks on the left side of the unit.



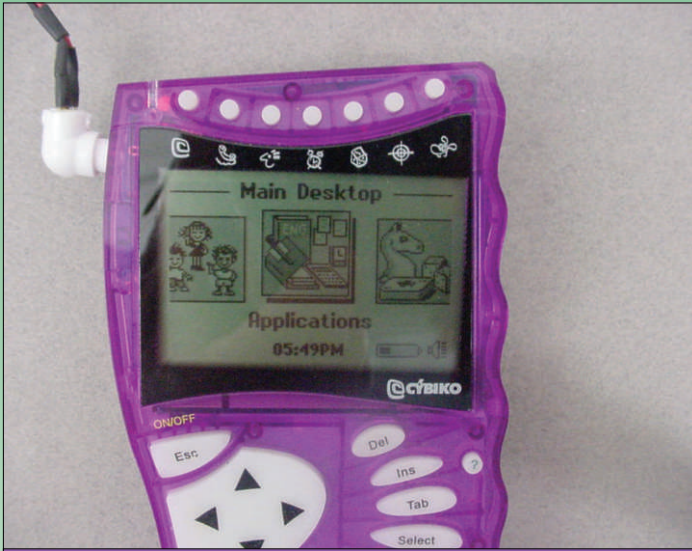


Figure 3: In the LCD screen, you can see three of the icons in the Main Desktop. Only the center icon has its name displayed. If I press the ENTER key, this is the group of applications that would be displayed.

If you missed this information, you can find it again by pressing the ? button on the right top of the keypad. The level of the System Pack is listed at the bottom of the LCD (you'll have to scroll down). There is a large, four position button on the left of the Cybiko keypad that has four arrows printed on it. Use this button to scroll across the LCD. If the system pack is version 57 or higher, then you don't need to update it.

Updating the System Pack and Erasing Old Applications

Connect your Cybiko to your PC and start it. Next, start the web browser on your PC and visit the Cybiko website. Now, start the CyberLoad software on your PC. In CyberLoad, click PORT in the menu and select the PC's serial port that is used by the Cybiko. Notice that CyberLoad opens two windows. On the right window is a list of applications currently loaded in the Cybiko. On the left window is a list of applications currently available on the Cybiko website. CyberLoad will determine the System Pack currently on the Cybiko. If your Cybiko doesn't have the latest version, then CyberLoad will ask if you want to upgrade the System Pack. Definitely upgrade it if it is not at least System Pack 57. To upgrade the System Pack, click the OK button.

If you are upgrading your System Pack and there is not enough free memory in your Cybiko, then CyberLoad will notify you. If you don't have enough memory, then you need to select applications on the right side of the window (those currently in your Cybiko) and delete them to make room. To delete applications, click on the application that you don't want and then click the DELETE button. I deleted all the games on my Cybiko, since I wouldn't need them

for VTterm.

Afterward, CyberLoad will ask again if you want to update your System Pack. Now, click the OK button. Upgrading will take several minutes. During the update, a game called Branch is available on your PC for your entertainment.

After updating the System Pack, the Cybiko will reset. Your Cybiko now has the latest System Pack. Close CyberLoad.

Downloading VTterm and CommPort Into the Cybiko

Start the SDK Console. You'll find the Console program in the SDK folder. If you start the Cybiko at this point, the Console program will display all messages generated while the Cybiko boots up. After the Cybiko has finished booting, click FILE in the Console's menu. Click Send File(s) in the pull down menu. Select these two files: vtterm.app and comport.dl. Click the OPEN button. The files are quickly loaded into the Cybiko. Shut down the SDK Console and the Cybiko.

To shut down the Cybiko, press the ESC key and hold it down. After a moment, the Cybiko goes into Suspend Mode. Continue holding down the ESC key and — a few moments later — the unit shuts off. Disconnect it from the PC.

On one of my Cybikos, I ran into a problem running the SDK Console after performing a System Pack update. I solved this problem by uninstalling both CyberLoad and SDK and then reinstalling the SDK.

Running and Configuring VTterm

After booting the Cybiko, the Main Desktop is displayed on the LCD. Only three icons are displayed at a time. There are more icons, but they are off the LCD. Your icons include Games, Applications, and CyCommunity. These icons are like groups in the old Windows. They are not programs, but they contain program icons. You select an icon by using either the left or right arrow key to move across the icons. As you pass an icon, it moves into the center of the screen, where its name is displayed. When the icon is centered and named, pressing the ENTER key selects the icon.

Scroll over to the Applications icon on the Main Desktop and press the ENTER key. Now, the LCD displays the Application Group's program icons. Scroll over to VTterm and press ENTER. If, at anytime, you make a mistake, press the ESC key to go back one level. When VTterm starts, the Cybiko gives a musical beep. Press any key to pass the introduction screen or just wait until after the message scrolls through. You're now staring at a blank screen with a cursor in the upper left hand corner.

We have to configure the terminal settings. Press the SELECT key. The options displayed for VTterm

include the following:

Baud Rate
Data Bits
Stop Bits
Parity
Handshake
Font Size
Local Echo (which is list below the bottom of the display)

Use the UP and DOWN arrows to select the setting you want to change. As you scroll over a setting, it is blocked in reversed text. Press the ENTER key to toggle through the possible options for that setting. When you select a setting, the screen blanks momentarily and the cursor jumps back to the Baud Rate setting.

When you're finished configuring VTterm, press the ESC key. The settings are sticky, so next time you start VTterm, the options you last selected remain in effect. The two Terminal Settings I changed are Baud Rate and Font Size.

I use 1200 baud, since my applications don't send huge amounts of data. I also use a slow baud rate to increase the reliability of my communications. I use the 4 x 6 font so I can display plenty of text without making it too small to read. The size of the font refers to pixel size and the options are 5 x 7, 4 x 6, and 3 x 5. At 4 x 6, I can display 32 characters across the screen and show 13 lines of text.

To get out of VTterm completely, press the ESC key. The application will ask for confirmation, so press the ENTER key. If you didn't mean to get out of VTterm, press the ESC key or arrow over to Cancel and then press the ENTER key. You'll note that it takes the Cybiko a few seconds to switch applications and the LCD displays the spinning Cybiko spiral. Press the ESC key again to get back to the Main Menu.

Now, shut down the Cybiko by holding the ESC key long enough to bypass suspend mode.

Building the Serial Cable Adapter

My BASIC Stamp 2 applications use a female DB-9 connector, just like the Board of Education. The end of the Cybiko serial cable also uses a female DB-9 connector. I found it easy and less expensive to make my own adapter cable, but you could purchase one. Be sure to get an adapter that switches the RXD and TXD lines.

To make your own cable, follow these steps:

Materials

- DB-9 male serial connector with solder cups (two)
- DB-9 housing (two)
- Stranded, #24 AWG wire
- Thin heat shrink
- Hot glue

I was able to get my parts at RadioShack.

Procedure

Since most microcontroller applications communicate over a simple serial interface, the adapter only needs three wires.

- Cut three lengths of wire. The exact length is not important, as long as the wires are the same length (1' is good).
- Strip 1/4" of insulation from both ends of all three wires.
- Solder one end of each wire to the following cups of the first DB-9: 2, 3, and 5
- Cut six pieces of heat shrink, about 1/2" long.
- Slide short lengths of heat shrink over the wires and cover the soldered connection.
- Slide the remaining pieces of heat shrink on the wires, one piece of heat shrink per wire.
- Solder the free end of each wire to the following cups of the new DB-9: From pin 5 to pin 5, from pin 2 to pin 3, and from pin 3 to pin 2.

Note that pin 5 (ground) is the same connection on both DB-9s; however, pins 2 and 3 are switched.

- Slide the remaining three pieces of heat shrink over the soldered connection of the second DB-9 connector.
- Shrink the heat shrink.
- Get the glue gun hot.
- Apply a thin coating of hot glue over the back of both DB-9 connectors, coating the solder cups in the back.
- Lay down a coat of hot glue in the bottom half of a housing.

Note: Do not get glue in the bolt holes.

- Set a DB-9 into the bottom housing.
- Fill remaining voids with hot glue.

Note: At this point, the glue may be getting too hot.

Figure 4: The Cybiko, with its original cable and my cable adapter.



Unplug the glue gun while you finish.

- Fill the bottom of the second half of the housing.
- Close the housings together, trapping the DB-9 and its wires inside.
- Bolt the housing together.
- Back fill open voids in the cable opening of the housing.

Repeat this process with the second housing.

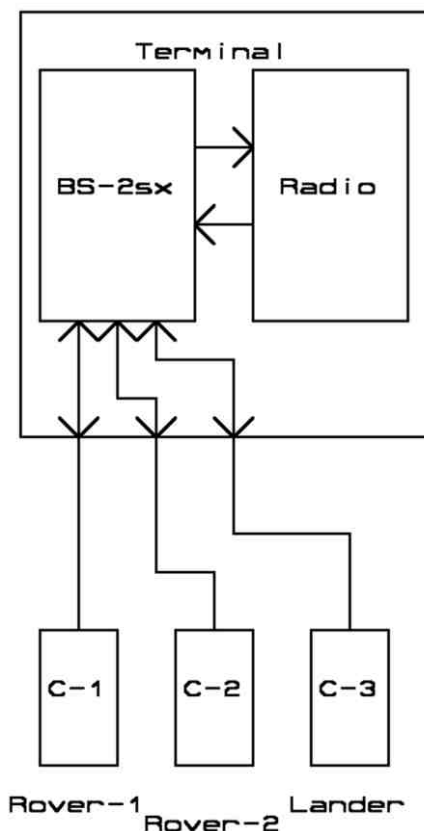
When the glue cools, you will have a solid plastic housing that acts as a strain relief of the Cybiko adapter cable.

A Back-up Power Supply for the Cybiko

There's nothing worse than having an application ready to rock and roll, but no way to tell it to go. This is the situation you face when the batteries in your Cybiko die. To prevent this embarrassing situation, carry a back-up battery for your Cybiko.

Here's how you can make your own:

Figure 5: Within the Mission Control terminal's box is a BASIC Stamp, a two-way radio, and supporting circuitry. Mounted to the outside of the box are three serial data ports and indicator LEDs. There's also a programming jack so the box doesn't have to be open to update the terminal's program.



Materials

- Four AA battery box
- 9 volt battery snap
- Power connection is through a power plug adapter. The size is 3.4 mm OD by 1.3 mm ID. Note: This is the same as RadioShack's Adaptaplug "H" 273-1711.
- Heat shrink tubing

Again, I was able to get my parts from my local RadioShack.

Procedure

- Tin the short pins on the back of the power plug adapter.
- Strip about 1/2" of insulation from the ends of the 9 volt-battery snap.
- Slide two short lengths of heat shrink over the two wires in the battery snap.
- Use a DMM and determine which pin on the back of the power plug is the center connection of the plug.

Note: Like most electronic devices, the Cybiko uses a positive center for its adapter.

- Press the tinned end of the red wire of the battery snap in contact with the tinned pin that you determined was the center contact of the power plug adapter.
- Heat the two and melt the solder between them.
- Repeat these procedures for the black wire of the battery snap and the remaining pin of the power plug adapter.
- Snap the battery snap on the four AA battery holder.
- Load four AA cells into the holder and you're done.

Making a Hi-Tech Reset Device

On occasions, I have seen my Cybikos lock up while running the VT-100 emulator. When this occurs, your only option is to reset the Cybiko and then go back into VTTerm. You can reset the Cybiko by pulling a battery, but this requires that you remove two small screws in the battery cover.

Fortunately, the Cybiko was designed with a reset button. To reach it, you need a fine-tipped point. A small jeweler's screwdriver will do it, but I found a simpler solution. Get a large paper clip and unfold one of the loops from the clip. This end fits inside the reset hole on the side of the Cybiko. The remaining folded portion of the paper clip is your handle.

Sample Application

I'm designing a micro-lander and a set of micro-rovers for a Near Earth Asteroid (NEA) exploration simulator. When it's complete, three individuals will play the parts of Mission Control specialists as they attempt to rescue the Earth from an impending asteroid collision. The keypads for communicating with the micro-lander and rovers are

three Cybikos. Figure 5 is a block diagram of the Mission Control terminal and some of the software I use for communications between the Mission Control terminal and the Cybikos.

In turn, each Cybiko is given a chance to request control of its element on the asteroid's surface. The individual in control of that particular element monitors his or her Cybiko for a request from the terminal. If they want to send a command to their element, then the controller presses the letter Y. The BASIC Stamp looks for either a lower case or upper case letter as the proper response. If the response is a not a Y, then control goes to the next Cybiko.

Here's a sample of the software:

```
i120          CON 18447  '1200 n81 inverted
rover1LED     CON 15    'rover-1 port LED
rover1RXPort  CON 1     'rover-1 port rx
rover1TXPort  CON 0     'rover-1 port tx
commandCharacter VAR Byte 'inputted command

SEROUT rover1TxPort,i1200,[CR,10,10,"ATTN ROVER-1|Y|N>"]
HIGH rover1LED      'turn on rover 1 indicator
'read a single character
SERIN rover1RXPort,i1200,[commandCharacter]

LOW rover1LED      'turn off rover 1 indicator
'echo the inputted command
SEROUT rover1TxPort,i1200,[commandCharacter]

IF commandCharacter = "Y" THEN Command_Rover_1
IF commandCharacter = "y" THEN Command_Rover_1

Check_For_Rover_2:
:
:
:
etc.
```

I hope you find the Cybiko to be a great tool, like I have. If you feel comfortable with programming in C for the CyOS, please create a VT-100 terminal program that adds the radio function of the Cybiko to its VT-100 emulator. I'd love to place a Cybiko on one of my rover projects and communicate between the rover and myself over the Cybiko's built-in radio link. **SV**

ABOUT THE AUTHOR

L. Paul Verhage is an electronics teacher at the Dehryl A. Dennis Professional Technical Educational Center in Boise, ID. He began working in the amateur near space field in 1994 and has accomplished over 40 missions. His book, *Amateur Near Space With the BASIC Stamp 2p*, will be published this year by Parallax.



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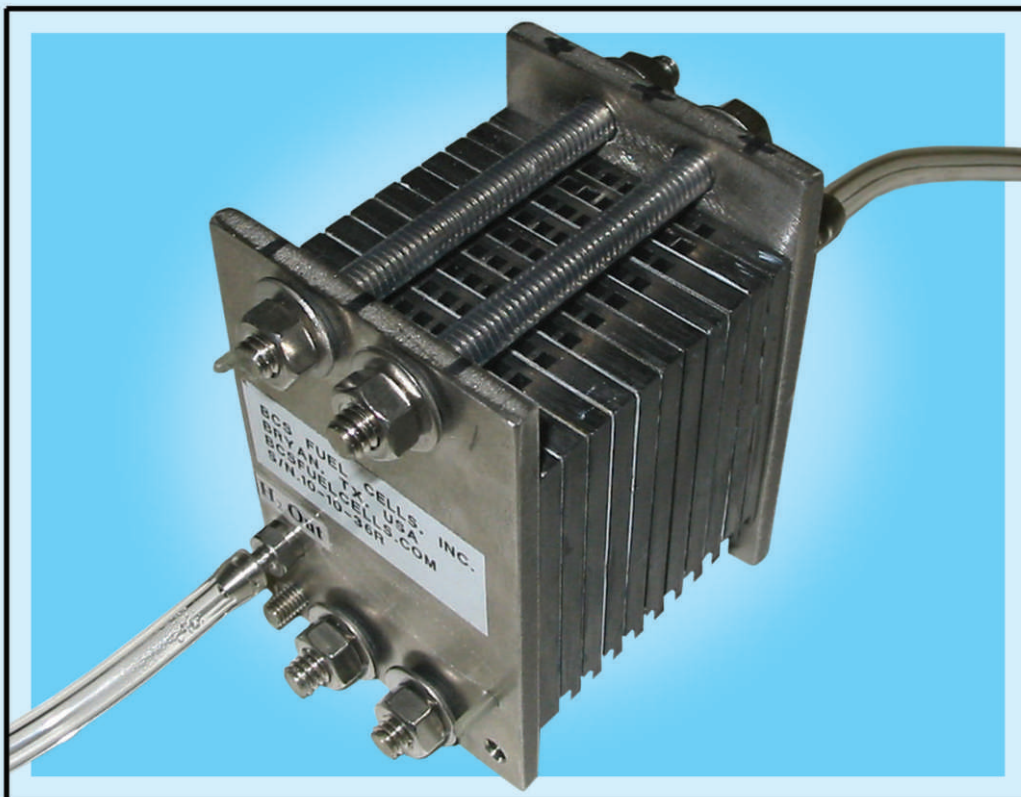
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FUEL CELL POWER



— by Alexander Wilhelm —

My project for the summer was mobile robots and micro fuel cells. The details: 20 custom-built mobile robots — dubbed “MechBots” — are used in a fourth year mechatronics course at Queen’s University in Kingston, Canada. Based on a BASIC Stamp 2 processor, they have a separate PWM controller to control two Barber-Coleman DC motors.

Various sensors and accessories can be mounted on the prototyping area using LEGO bricks — every robot builder’s favorite “toy.” The robot’s existing power system consists of a 12 V sealed lead acid battery with a nominal rating of 2.2 Ah; my job was to replace this with a suitable fuel cell.

POWER REQUIREMENTS

The first step involved was determining how much power the robot actually needed. Thanks to a current shunt and a PC data acquisition card, a large amount of data was quickly accumulated.

Evaluating it took a little more time, but I found that — driving normally — the robot required about 6 W. When stalled with many of the peripherals on, a peak draw of 14 W was observed.

Comparisons to Parallax’s BOEbot — which produced similar torque and used only 2 W for normal driving — showed the MechBot to be a bit of a loser in the efficiency department.

When using an expensive power source, it makes sense to look for system efficiencies, but we decided to stick to our trusty and hefty MechBot for comparison purposes.

CHOOSING A POWER SYSTEM CONFIGURATION

In order to supply all the power that might be required, the fuel cell would need to be capable of generating 14 W.

However, most of the time, this expensive capacity would go unused. Thus, the possibility of some sort of hybrid arrangement with either batteries or capacitors was in my mind from the



Figure 1. The fuel cell stack from BCS Fuel Cells, Inc.

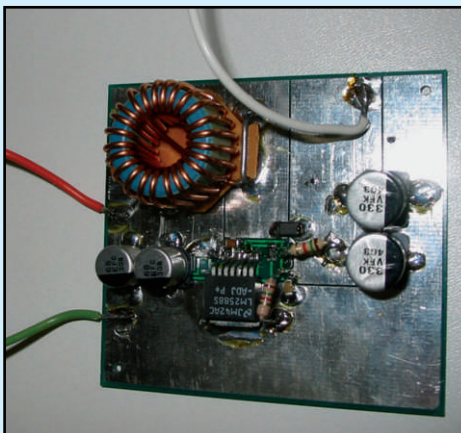


Figure 2. The National Semiconductor LM2588 evaluation board boosts the fuel cell output voltage from as low as 3.5 V to 13.5 V.

very beginning.

While it's difficult to determine how much average power something as unpredictable as a mobile instructional robot needs, some number crunching suggested an 8 W stack would handle regular demand well and a series of super capacitors could jump in when needed. Demand spikes are something fuel cells aren't that great at dealing with due to the "slow" chemical processes involved.

A battery hybrid was also tried, but it required fairly complex charge circuitry to maintain. This was where I first realized that – though SSOP may look like a DIP package on screen – there are some rather serious size differences, once in hand.

CHOOSING A FUEL

While most people know of fuel cells that run with hydrogen, it is cells that can use methanol directly that are attracting a lot of attention for use in portable applications. In principle, methanol has a lot of advantages, the most important being that it is easy to handle compared to hydrogen, which is a very light gas at room temperature.

However, there are problems associated with un-reacted methanol crossing through the membrane, reducing the power output.

Though developers are feverishly working on this, currently a low concentration of methanol or a

complex recirculation system must be used. In the end, the lack of suitable off-the-shelf methanol systems meant hydrogen was my only choice, despite the difficulty of storing it.

Even though I was using hydrogen, finding a suitable fuel cell stack proved tricky, as much of the development at the 10 W level lies in the proprietary domain of the likes of Toshiba and small start-up companies, such as Manhattan Scientifics. The stack that was ultimately selected – a 10 W unit from BCS Fuel Cells, Inc. (Figure 1) – won out because of its ability to use ambient air rather than pure, surized oxygen and its ability to self-humidified from the water it generates.

It also had the highest available voltage, ranging from 10 V at no load to about 5 V at 2 A. Its fairly high weight and larger than necessary power output were drawbacks, though.

FUEL STORAGE

The mention of hydrogen conjures up images of the *Hindenburg* for many people. The truth is that hydrogen is no more dangerous than other fuels; in fact, it is quite safe, if handled properly.

That being said, storing it in a floating balloon above the robot is not a good choice, although it is, perhaps, an interesting way to reduce weight. This is due to the large balloon size that would be needed.

Instead, two options currently exist for effective, small-scale hydrogen storage. The traditional one is to store it as compressed gas, which results in a fairly light – if aluminium or carbon composites are used – but still fairly bulky tank.

Unfortunately, the high pressures (up to 300 bar/4,500 psi) require refilling to be done by the gas supplier and necessitate a fair deal of heavy plumbing on the robot.

The alternative is storage at a low pressure in a metal hydride; the hydrogen

WHAT IS A FUEL CELL?

A fuel cell is a device that converts chemical energy directly into electrical energy. Several different types exist, but the most prevalent for small applications is based on a Proton Exchange Membrane or PEM. This membrane allows only protons — hydrogen atoms with the electron removed — to pass through. The electrons then must travel through an external circuit, powering the device.

On the other side of the membrane, oxygen combines with the protons and electrons to form

water ($\text{H}_2 + 1/2 \text{O}_2 \Rightarrow \text{H}_2\text{O}$). Each cell outputs less than 1.2 V, so cells are arranged in stacks in order to achieve higher voltages. The desired amperage is reached by increasing the membrane area. In order to operate, the PEM must remain moisturized, which is normally achieved by humidifying one or both of the supply gasses and keeping the operating temperature below 80° C. High temperatures and pressures improve performance, but require more peripheral systems.

literally becomes part of the metal powder in the tank. This reduces size considerably, but — being a metal — creates a fair amount of weight, although the lighter plumbing offsets this. Both options are difficult to find in the desired size and volume range; a small metal hydride tank was chosen more for the novelty of this storage medium than anything else.

BALANCE OF PLANT COMPONENTS

Having a fuel cell stack does not a functional system make; unlike a battery, several peripheral or “balance of plant” components are required before electricity can be supplied to the robot. With fuel cells, voltage drops quickly as load increases. High voltage ranges are also not practical to implement at low power levels.

Fortunately, excellent DC/DC converters designed for battery-powered electronics already solve this problem. An evaluation board from National Semiconductor with an LM2588 chip (Figure 2) was capable of boosting voltages from as low as 3.5 V up to a consistent 13.5 V level with over 90% efficiency.

Before electricity can be produced, the cell must be supplied with fuel. This is accomplished by a pressure regulator made by Beswick Engineering that is designed for metal hydrides. It turns out that, although the hydride tanks are filled at up to 435 psi (30 bar), they only release at up to 7 psi (0.5 bar), making the regulation down to the suggested 3 psi rather trivial.

Although some of the water produced

by the fuel cell is used to humidify the membrane and some evaporates, eventually there may be a build-up that hinders performance. To alleviate this, the stack is occasionally purged by blowing through hydrogen. As explained in the sidebar, this is controlled by the Stamp itself, in concert with a small solenoid valve.

ASSEMBLY

Switching to hydrogen power was not simply a matter of dropping in a fuel cell in place of the battery because of all the peripherals already mentioned. While I had originally been hoping to place a good deal of the components in the space vacated by the battery (Figure 3), the fuel cell turned out to be just a little too high to go underneath the robot’s deck and would not operate with its air passages sideways.

The tank also did not go under the robot, as it seemed like it could benefit from some of the stack’s heat;

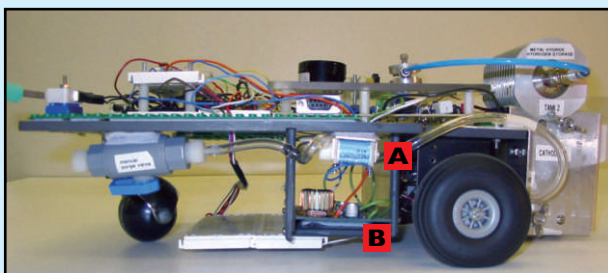


Figure 3. Side view of MechBot showing the solenoid purge valve (A) and power conversion board (B).



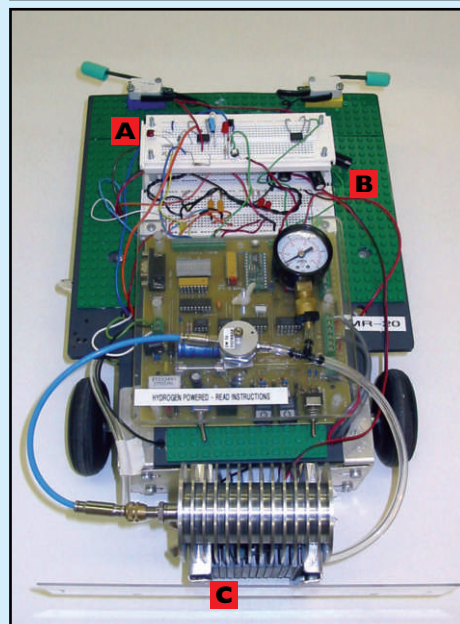
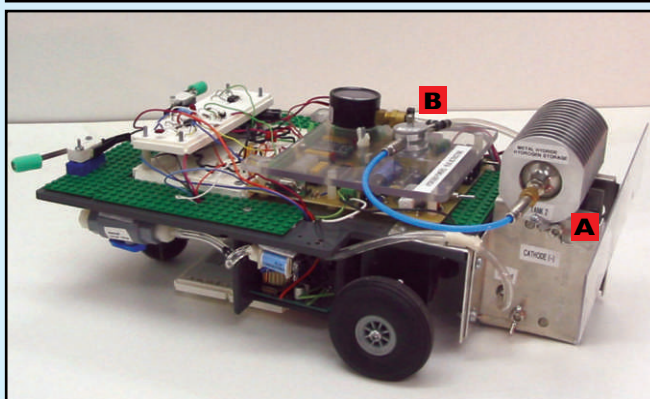
Figure 4. A custom heatsink was created for the metal hydride tank, and fitted to the top of the fuel cell stack.

equipped with a custom heatsink (Figure 4), it now sits above the fuel cell, hanging off a bracket on the robot’s rear (Figures 5 and 6). While this is by no means a BMW-like weight distribution, the MechBot is hefty enough for it not to matter.

The remaining bits of plumbing and power conditioning are attached with VELCRO® to the robot in various places for easy removal and so they do not interfere with its normal operation.

Figure 6. Top view of MechBot showing the voltage and current sensing circuits (A), black supercaps (B), and the fuel cell stack (C).

Figure 5. Fuel cell management from the metal hydride storage tank (A) and the low pressure regulator (B).



MechBot Fuel Cell System Schematic

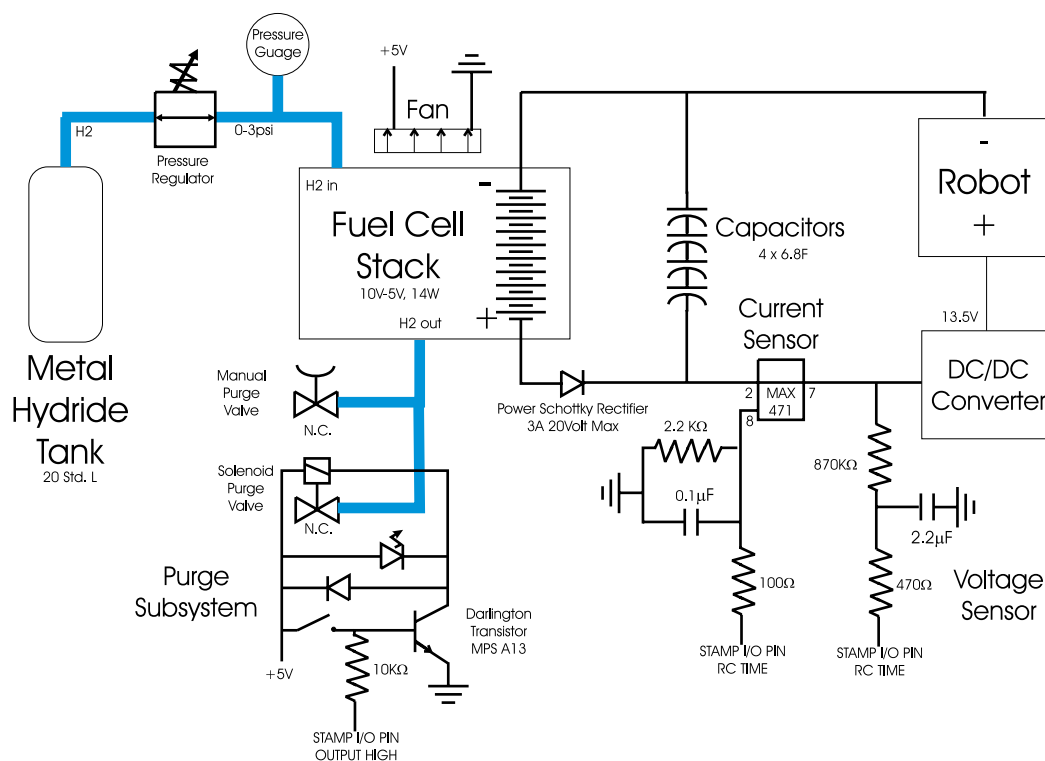


Figure 7. Both hydrogen and electricity flow paths are shown in this schematic of the fuel cell subsystem.

A schematic of the whole system is shown in Figure 7 and parts are listed in Table 1.

TESTING AND RESULTS

For a prototype, the fuel cell powered MechBot came together quite

well, running for about two hours on one tank and needing about 20 minutes for a refill (the metal hydride needs time to react with the hydrogen). The battery could run the same program for six hours with degrading performance, but then needed to be recharged for 10 hours. The fuel cell

They never seemed to fill properly or as quickly as suggested, either.

Overall, the fuel cell system weighed 1,247 g (44 oz) compared to the battery's 980 g (35 oz); details about the power and energy densities are listed in Table 2.

THE BIG PICTURE

Anyone who uses batteries has, no doubt, spent some time cursing them. They never seem to last as long as desired and seem to take an eternity to recharge. Mobile robots, in particular,

REFERENCES

Dyer, C., "Fuel Cells for Portable Applications," 2002, *Journal of Power Sources*, pp. 31-34

"BASIC Stamp Rctime Tips," EME Systems,
www.emesystems.com/BS2rct.htm

Component	Details
Fuel Cell Stack	10 W-12 W 10 V-6 V air-breathing self-humidifying, BCS Fuel Cells, Inc.
Fuel Storage	MHS20 Metal Hydride Cylinder, 20 std. L. volume, GfE Hydralloy E60/0
Power Conversion	LM2588 Simple Switcher® 5 A flyback regulator evaluation circuit, National Semiconductor
Pressure Regulator	PRD2-2N1-1A ultra miniature two-stage pressure regulator, Beswick Engineering Co.
Hybrid Power	Four PowerStor Aerogel Capacitors, B1030-BR5685, 6.8 F each
Fan	Model KDE1204PFV1, 4 cm x 4 cm x 1 cm, rated at 12 V. 0.5W, SUNON
Solenoid Valve	V ² Digital Solenoid Valve, model V2201PV5S80, 5 V, 0.5 W, Parker/Pneutronics

Table 1. Fuel cell system specifications for MechBot.

	Energy (Wh)	Power (W)	Cost (US \$)	Cost/W (\$/W)	Cost/Wh (\$/Wh)	Energy Density (Wh/kg)	Power Density (W/kg)	Energy Density (Wh/L)	Power Density (W/L)
Battery Systems									
Lead Acid Battery (Portalac PE12V2.2)	22.75	40	\$22.70	0.57	1.00	23.21	40.82	62.65	110.16
<i>or</i>									
Lithium Battery (Ultralife UBP103450)	6.7	6.7	\$25.00						
X4	26.8	26.8	\$100.00	3.73	3.73	167.50	167.50	313.32	313.32
Fuel Cell Systems									
Basic:									
Fuel Cell		14	\$720.00	51.43			20.59		27.20
TOTAL with Hydride Tank & Peripherals	19.62	13.3	\$1,020.24	76.71	51.99	15.74	10.67	20.80	14.10
Hybrid:									
With Capacitors TOTAL	19.63	15.3	\$1,052.56	68.79	53.62	15.56	12.13	20.57	16.03
<i>or</i>									
With Lithium Battery TOTAL	26	20	\$1,046.22	52.57	39.59	20.40	15.37	27.31	20.57
Table 2. Comparison of power energy densities, as well as costs between old battery systems, final designs, and alternatives.									

are at the mercy of their batteries. Fuel cells have the potential to eliminate

these problems, but — right now — developers still have some work and,

undoubtedly, some cursing of their own to do before fuel cells are ready

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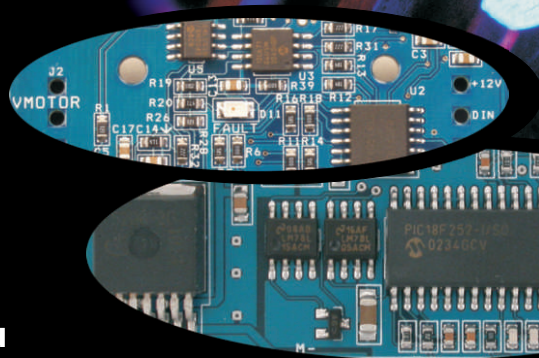
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FUEL CELL POWER

for the marketplace. Several companies have promised products within the next year or so — keep an eye out for a fuel cell powered laptop or cell phone near you.

One of the big advantages of fuel cells over batteries is that fuel cells decouple energy storage from power production. This makes it easy to provide more energy (in the form of fuel) as needed and, as long as fuel is supplied, the available power stays the same.

In effect, a fuel cell gives similar benefits to an internal combustion engine, but it is also quieter, more efficient, non-polluting, and more easily scaled down. However, it is more complex than a battery and its 30-50% fuel efficiency can't compare to the over 90% cycle efficiencies of batteries.

HYDROBOTICS — THE WAY OF THE FUTURE?

If a robot currently uses lithium batteries, weight is probably a significant

factor and cost is a lesser issue. For such a situation, fuel cells — probably in tandem with capacitors or a small battery — will become attractive in the future, once component weights are optimized. If long run times are important and power requirements are relatively low — say, for some sort of security surveillance robot — a fuel cell becomes even more attractive.

On the other hand, if a robot currently uses a lead acid battery, cost is probably more important than weight. Though fuel cells already compete well compared to lead acid on a weight basis, a prediction of \$5.00/W for portable fuel cells (Dyer) still remains an order of magnitude higher than the trusty lead acid. Nevertheless, it is interesting to speculate how many more rooms a Roomba® vacuum could accomplish in one go if it ran with a fuel cell — the charge time would definitely be eliminated, but you would have to supply the robot with fuel.

Most amateur robot builders won't be rushing out to get a fuel cell

for their next project, given the current costs and lack of availability, but this will undoubtedly change in the near future. Already, a fair number of smaller hobby fuel cells exist and are available at such sites as www.fuelcellstore.com

However, the selection of balance of plant components is poor and few are optimal for portable applications. Nevertheless, this project proves that, if you want fuel cell power for your robot, it can be done! **SV**

ABOUT THE AUTHOR

Alexander Wilhelm is a fourth year undergraduate student at Queen's University in Kingston, Canada. Last summer, he received an NSERC (National Sciences and Engineering Research Council of Canada) research award for the project described in this article and got a chance to explore robotics further. He can be reached by Email at Alexander.Wilhelm@gmail.com

PURGING WITH THE STAMP

The fuel cell periodically fills up with too much water, causing performance to drop. This can be remedied by opening the solenoid valve and blowing a tiny amount of excess hydrogen through, which quickly diffuses in the room. When to purge so as to minimize hydrogen wastage, though?

Water production is dependent on the current drawn, the stack temperature, air temperature, and air humidity — all of which can fluctuate as the robot operates. The fuel cell has an operating curve (Figure A) that can be approximated by a straight line. By comparing measured voltage and current values to this line — or, specifically, the intercept of this line — it can be determined if performance has actually dropped.

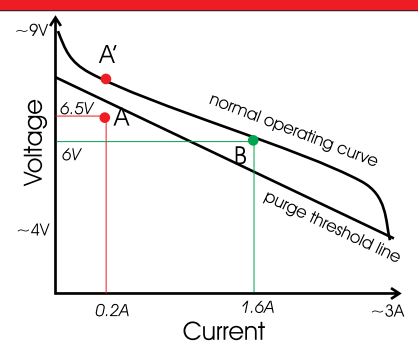
The voltage is sensed by the

stack using a simple RTime circuit. The current is sensed using RTime and a MAX471 current sensing chip. Both circuits are modelled after those found on EME Systems' tips and tricks page. You could also use an A to D converter for better precision with a slightly increased cost. Alternatively, similar functionality with a slight increase in hydrogen wastage would be achieved by simply purging at set time intervals.

After the raw sensor values are acquired and converted to more meaningful units, perform a series of condition checks to see if the performance has indeed dropped or if it's just an anomalous sensor reading. This can be seen in the sample source code — available online. Some trial and error led to the discovery that the voltage, V , added to

current, I , should remain above 720 for proper performance (that is, the equation of the line is $V = -I + 7.2$). For example, at point A, with a voltage of 6.5 V and a current of 0.2 A, the result of 670 lies below the purge threshold — normal operation would be at A'. On the other hand, point B is at 6 V and 1.6 A, giving a result of 760 — well above the threshold.

Figure A. Fuel cell operating curve



FIRST* FRENZY 2004 PART 4*

BY BRUCE & EVAN WOOLLEY

Welcome to the frenzied conclusion of Team 1079's 2004 FIRST season. We rejoin the team on the night before the sectional hosted by the awesome Team #22 at Chatsworth High School. At the beginning of the build, we swore to have the robot driving weeks before the deadline and, of course, on

the Friday evening/Saturday morning of the last build weekend, we were frantically trying to get the robot to drive — even to move — for the sectional.

We have discovered, like so many FIRST teams before us, that the intensity level is inversely proportional to the time left. The best example of this phenome-

non was the rising Dad Con (stress indicator of the dad) level. Somehow, everyone survived until 3:00 Saturday morning, when we gave Modos its first comprehensive test. Everyone present was overjoyed to see the arm move up and down smoothly, but a lack of sleep made for a subdued reaction.

Standing, from left to right: Bryce Woolley, Jairus Ciocon, Bryant Nelson, Kristen Baber, Justin Lyons, Ryan Potts, Jack Gordon. Kneeling: Evan Woolley.



Team members not pictured:
Evan Heid, Josh Larsen,
Austin O'Neal, Ivan Hoffman.

CLUB CREATE

* FIRST FRENZY 2004 PART 4 *



2004 LA REGIONAL

The Sectional

Later that morning, we arrived at the SCRRF sectional and our ecstasy over the fact that we had a working robot made a passable substitute for sleep. Another comforting aspect was seeing all of the tired faces on the members of other teams and watching everyone else doing last minute modifications, too; this let us know that we weren't alone in the rush to meet the deadline.

Despite the fact that everyone involved was running on next to no sleep, the sectional was invigorating, in a way. This was our first chance to see what other teams had come up with and the diversity of designs and ideas was impressive.

The sectional was also our first opportunity to weigh Modos as whole and we were surprised to find that our robot needed to go on a diet. We needed to lose 10 pounds! Atkins takes longer than an hour, so we extracted

the onboard compressor, removed the top fan plate, and reluctantly cut our Lexan plates in half. When we were still overweight after these modifications, the team grudgingly decided to sacrifice some "cool factor" and remove the diamond plate from the kicker. Surgery was interrupted by our first match and our excitement made the loss of the diamond plate seem insignificant.

One particularly exciting element of the practice match was that it gave us our first opportunity to see our autonomous mode in action. The autonomous mode was certainly ... unexpected. Modos spun around and crushed its fingers against the driver wall. Other than that, though, we were very happy to see Modos driving around. Despite the harsh reality that the pneumatic cylinders were damaged beyond repair, the amputation of the fingers helped our weight issues.

Other than that hiccup, everyone was satisfied with our performance at the sectional. We were out driving in every match and, between matches, we made a great deal of progress filing down Modos' sharp edges.

Now We Wait ...

After getting a chance to really bond with our creation at the sectional, we had to pack Modos into a crate and ship it away. We would reunite with it several weeks later at our final competition. We were actually kind of sad to see the crate leave, too, because we put so much effort into painting it. Most teams decorate their crates; we're not just weird.

Then, one day after school, the robot was gone and the whole team let out a big sigh of relief. Some people might think that the teams finally get a chance to relax at this point. Other than catching up on sleep,

"relaxation" time is filled with strategizing about the game and preparing aesthetics. The pit area in the FIRST competition is not just for work; it is also a great place to promote your team. Like most teams, we spent the weeks between shipping and competition preparing posters and banners to let everyone who would pass by our pit area know what Team 1079 is all about.

After weeks of building and strategizing, everything came together at the LA Regional. We arrived early Thursday morning and anxiously awaited entry into the Sports Arena so we could uncrate our robot and set up our pit area. Since we took care of Modos' weight problem at the sectional, we passed tech inspection swimmingly.

The first order of business — which is always very important to our team — was to attach decals and stickers that recognize our sponsors to the robot. We're very aware that our team wouldn't exist without our sponsors and we like the look that the decals give our robot — it's kind of like a race car.

The LA Regional

The FIRST competition spans three days and, mercifully, the first Thursday is set aside for tech and practice. Even though these matches were just for practice, we were all elated at our fine performances. The only thing that was left between our current situation and perfection was an autonomous mode. A few minor tweaks and everything would be flawless — or so we thought.

We had an early match on Friday, so we didn't have a chance to tweak the program before that time. We fared well, except for our autonomous mode, where we simply spun in place. After our first match, we were eager to make the final adjustments to the code. Unfortunately, our team didn't have a resident programming expert, so we had to rely on gracious volunteer work from other FIRST participants to fine tune our program.

Ironically, the correction of a syntax error scrapped our program. Disaster!! The robot wouldn't move at all in any mode! Modos didn't even budge in the



2004 TEAM PIC



second match and we were desperate to restore its functionality for our third match. Thanks to some impromptu programming heroics from Mark Miller of Team 294 (Beach Cities Robotics) and the awesome Punar Sikka from Team 696 (Clark Magnet), Modos was up and running for match three – with a perfect autonomous program! All it did was move backward for a few seconds, but we had altered our definition of perfection by this time.

Even though the program incident was stressful, it was a sparkling example of gracious professionalism in action. In a more cut-throat and competitive environment, opposing teams would have been delighted by the fact that our robot was incapacitated. In the cooperative environment of FIRST, however, two team leaders from our rival teams went out of their way to make sure that we had a working robot. Modos was out and driving for the rest of the day, largely due to the professional attitude exhibited by fellow teams.

The final day of competition was on Saturday and our day began with our last few preliminary matches. We did reasonably well, but not well enough to qualify in the top “seeds” for alliance picking. Our robot could not “hang” – which was worth an extra 50 points. Every robot that we were paired with in matches either could not hang or was not able to do so in our match. We learned that the 50-point advantage that hanging robots had was largely responsible for their success in competition.

Next year, we will build to perform ALL tasks. One of our other big focal points on Saturday was to impress the judges. The majority of the awards given out in FIRST actually have nothing to do with what goes on in the field. The most prestigious awards are given to the teams that best express and exemplify the ideals of FIRST, such as gracious professionalism and inspiration in engineering.

This year, we hoped to be in contention for awards like the Imagery Award or the Quality Award. The basis for winning an award was what the team could tell the judges about their

robot, team, and the learning process in a concise and clear manner. Even though most of the judges are professional engineers, the ability to convey the ideas behind the team’s design and the team itself is an important skill. In the real world, the ability to effectively communicate your ideas is one of the most important parts of being an engineer. The elements of our team that we stressed were our attention to detail, the simple elegance of our designs, and the overall robustness of our robot.

Catch That Hawaiian Shirt!

In the FIRST promotional video, Dean Kamen says that he dreams about making science and technology as exciting as sports are to today’s youth. He says he wants kids to look up to engineers as heroes, just as they look up to sports stars. It looks like Dean Kamen’s vision may be coming true. In the time between the preliminary matches and the championships, members from Team 1079 were busy trying to impress the judges.

Bryce caught a glimpse of a Hawaiian shirt flashing by and was able to bring the engineer wearing it back to our pit area. The Hawaiian shirt belonged to none other than Dave Lavery, head of Solar System Exploration at NASA and co-designer of the FIRST games. Everyone on the team was honored by this visit from the famous scientist. To us, he was like a sports star; he had just made a three-pointer on Mars! Twice!

Due to his extremely busy schedule, Dave Lavery was only around long enough to look over our robot, Modos, give a quick explanation on how to calculate frictional losses in relation to the length of a wheel base with trigonometric functions, and – the best part – autograph our robot. His signature and message on our robot of “See you on Mars!!” are an



SPONSOR FLASH!

enduring testament to how FIRST allows high school students to interact with engineers from the highest echelons of science and technology.

The Finals and the Awards Ceremony

Soon after that memorable encounter, it was time for alliance selection. The top eight seeds would pick two other teams to form an alliance for the finals. Whenever called upon to join an alliance, a representative from the chosen team would come forward and, in all of the instances we have observed, “graciously accept” the



REPROGRAMMING



MODOS' FLAG

offer. This is just another example of how FIRST promotes cooperative competition, not cutthroat competition.

Despite our best efforts, Team 1079 was not chosen for the finals. It was still very exciting to watch the finals, however, because the finals showcased the most effective designs and such refined driving skills that they could be called art. The excitement of the last matches was great enough to make our team forget the disappointment of not being chosen.

One thing that a person who has never been to a FIRST competition wouldn't really understand is the tremendous energy. Music is constantly

playing and cheering fans fill the stands. If an oblivious bystander mistakenly walked in, he would think he stumbled upon a huge sporting event rather than a science competition. That excitement is amplified several times over in the finals while the last test unfolds, determining which teams will reign supreme. Watching it all unfold is a blast.

The awards ceremony followed shortly after the finals. Team 1079 was still hopeful about winning something. In the end, though, we did not win any special honors. Our mentors — Team 812, Midnight Mechanics of the Preuss School — did, however, win the Engineering Inspiration Award, which is the second most prestigious award in FIRST. We were overjoyed for our mentors because our team was one example of Team 812's efforts to spread the FIRST program.

The fact that the Engineering Inspiration Award is far more prestigious than an award for finishing well on the field gives insight regarding what FIRST is all about. As the name states, FIRST is about the inspiration of science and technology. This commitment to inspiration has led teams to teach classes and host camps in their communities on robotics to spread an engineering curriculum to other high schools, middle schools, and elementary schools. Some teams have gone as far as getting a FIRST Day declared in their community. Such dedication to inspiration is, well, inspirational.

Despite the fact that Team 1079 did not win any special awards, we were still very happy with our performance and effort. This year, we had a reliable robot (except for the programming incident) that was able to complete every task that we built it to complete.

One match in particular showcased all of Modos' abilities. We were able to grab a mobile goal, uncup it, push it under the ball drop, and recap it after several balls fell into

the goal when they were released from the top. One exhilarating performance like that was enough to make up for several less spectacular performances because that match demonstrated our successful design and construction. Satisfied with our performance and relieved that it was all finally over, we packed up and headed for home — already full of ideas for next year.

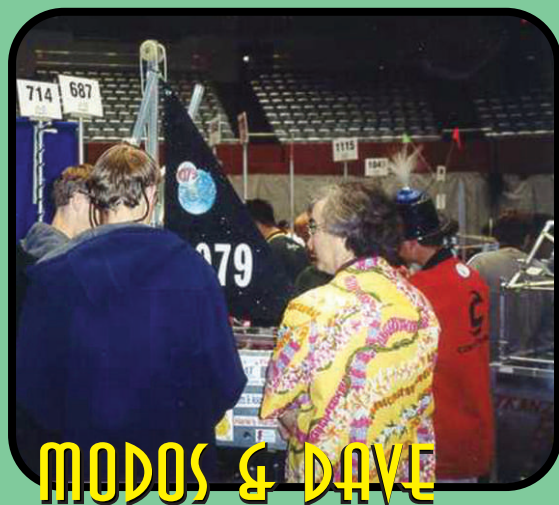
Beyond the Arena

Actually, it's not over. FIRST is truly a year-round effort — the quest to inspire and recognize the pursuit of science and technology does not end with the competition. A good example of the continuation of the FIRST program after the regular season is the JPL Open House. The Jet Propulsion Laboratory hosts an annual open house and FIRST teams are invited to showcase and represent the FIRST program.

While the biggest chunk of the time is spent explaining and promoting the FIRST program to the attendees, a field is also set up for us to demonstrate the game. Team 1079 has been fortunate enough to attend the open house two years running. There, we have been able to inspire kids to become a part of FIRST and generate interest in various teams' summer camp opportunities.

Along with being a great venue to promote FIRST, it's also an opportunity for us to pull the robot back out of the garage and play the game one more time — in a much less stressful environment. Spectators love to see real robots in action, but many become visibly disheartened upon learning that the year's competition had just been held the previous month.

Sometimes, it's fun just bringing the robots out to play again; such an opportunity existed in the Team San Diego Scrimmage, held in late May. Team San Diego is the group of San Diego area FIRST teams of which Team 1079 is a proud member. The Scrimmage was hosted by Madison High School, Team 1266 — the Devil Duckies — and was simply a fun opportunity to play with the robots again and



MODOS & DAVE



interact with other FIRST teams. Team 1079 offered only a small showing of team members, though, because a good portion of our team became involved with the Solar Cup Competition that was held the same weekend.

The excitement and fulfilling challenges of the FIRST competition prompted Team 1079 to get involved with other programs, such as the Solar Cup — a solar-powered boat race. Chaparral High School's overworked team (the Solar Cup kick-off was the same day as ours and the solar boat build time competed with the FIRST build time) still made an impressive rookie Solar Cup team. They came home with awards for their drive-train and technical design, thanks in part to the skills gained in the FIRST program. The Solar Cup team was entirely student driven and organized. Even though boats and robots aren't that similar, the same engineering principles and know-how apply.

Since FIRST Frenzy 2004, Team 1079 has made an effort to get its name out in our community. We've appeared several times in various local papers, the robot had a part in a school rally, and we put on a LEGO Mindstorms-based summer camp for middle schoolers as a fundraiser for our team. A new school year has begun and we have several new freshmen team members who are getting acquainted with Robot Central.

A Final Thought

The FIRST program presents an awesome opportunity for everyone involved. It provides real world experience at the high school level, preparing students for college and beyond. Not only is the practical knowledge valuable, but important connections are made into the world of engineering. High school students have the opportunity to meet and interact with real engineers



MATCH TIME!

(and famous ones, too) who can relate how science and technology offer a fun and fulfilling career.

Through the FIRST program, students start to see the relevance of their science and math classes. If you tell a student to figure out speed from a set of given information, you will probably get a groan. If you tell a student to figure out how fast the robot will go based on wheel sizes and motor specs, you will likely get a more enthusiastic response. Once the formulas that students learn in school cease to be dull homework and start to be part of a fun, challenging, and relevant project, learning becomes exciting and enjoyable.

A quote from Woodie Flowers —



MODOS LIFTING

Professor of Mechanical Engineering at MIT and co-designer of the FIRST games — sums up FIRST competition best, "It's the hardest fun you'll ever have."

Please visit **www.usfirst.org** to find out more about this program and/or to find a competition near you to watch. Regional events begin the first weekend in March through the first weekend in April, culminating in the Championship event on April 21, 22, and 23 in the Superdome in Atlanta, GA. Who knows — you may even see Team 1079 there! **SV**

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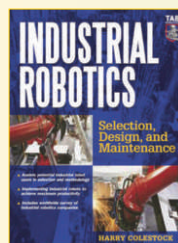
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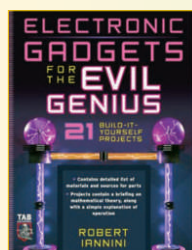
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by Gordon McComb

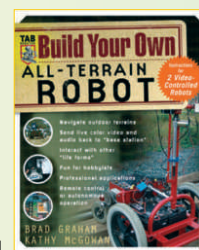
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Build Your Own All-Terrain Robot

by Brad Graham / Kathy McGowan

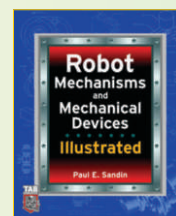
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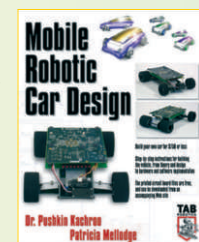
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by Gordon McComb

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Robotics Demystified

by Edwin Wise

There's no easier, faster, or more practical way to learn the really tough subjects. McGraw-Hill's *Demystified* titles are the most efficient, intriguingly written brush-ups you can find. Organized as self-teaching guides, they come complete with key points, background information, questions for each chapter, and even final exams. You'll be able to learn more in less time, evaluate your strengths and weaknesses, and reinforce your knowledge and confidence. **\$19.95**



Build Your Own Humanoid Robots

by Karl Williams

Build Your Own Humanoid Robots provides step-by-step directions for six exciting projects — each costing less than \$300.00. Together, they form the essential ingredients for making your own humanoid robot. **\$24.95**



PIC Robotics: A Beginner's Guide to Robotics Projects Using the PIC Micro

by John Iovine

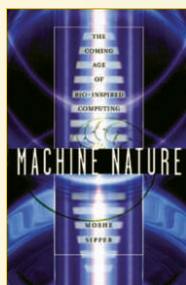
Here's everything the robotics hobbyist needs to harness the power of the PICMicro MCU! In this heavily-illustrated resource, the author provides plans and complete parts lists for 11 easy-to-build robots — each with a PICMicro brain. The expertly written coverage of the PIC Basic Computer makes programming a snap — and lots of fun. **\$19.95**



Machine Nature: The Coming Age of Bio-Inspired Computing

by Moshe Sipper

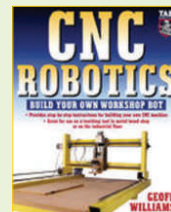
Despite being marvels of complexity and human ingenuity, computers are notoriously bad at learning new things and dealing with new situations. Researchers at the frontiers of computer science have turned to nature for solutions to the problem of machine adaptation and learning. By applying models of complex biological systems to the realm of computing machines, they have given rise to a new breed of adaptive software and hardware. In *Machine Nature*, computer scientist Moshe Sipper takes readers on a thrilling journey to the terra nova of computing to provide a compelling look at cutting-edge computers, robots, and machines now and in the decades ahead. **\$24.95**



CNC Robotics

by Geoff Williams

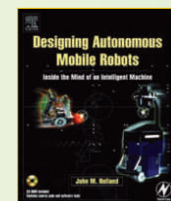
Now, for the first time, you can get complete directions for building a CNC workshop bot for a total cost of around \$1,500.00. *CNC Robotics* gives you step-by-step, illustrated directions for designing, constructing, and testing a fully functional CNC robot that saves you 80 percent of the price of an off-the-shelf bot and can be customized to suit your purposes exactly, because you designed it. **\$34.95**



Designing Autonomous Mobile Robots

by John Holland

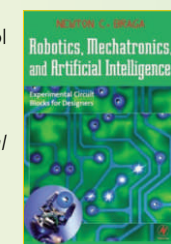
Designing Autonomous Mobile Robots introduces the reader to the fundamental concepts of this complex field. The author addresses all the pertinent topics of the electronic hardware and software of mobile robot design, with particular emphasis on the more difficult problems of control, navigation, and sensor interfacing. Its state-of-the-art treatment of core concepts in mobile robotics helps and challenges readers to explore new avenues in this exciting field. The accompanying CD-ROM provides software routines for the examples cited, as well as an electronic version of the text. **\$49.95**



Robotics, Mechatronics, and Artificial Intelligence

by Newton C. Braga

Accessible to all readers — including secondary school students and amateur technology enthusiasts — *Robotics, Mechatronics, and Artificial Intelligence* simplifies the process of finding basic circuits to perform simple tasks — such as how to control a DC or step motor — and provides instruction on creating moving robotic parts, such as an "eye" or an "ear." Though many companies offer kits for project construction, most experimenters want to design and build their own robots and other creatures specific to their needs and goals. With this new book, hobbyists and experimenters around the world will be able to decide what skills they want to feature in a project and then choose the right "building blocks" to create the ideal results. **\$31.95**



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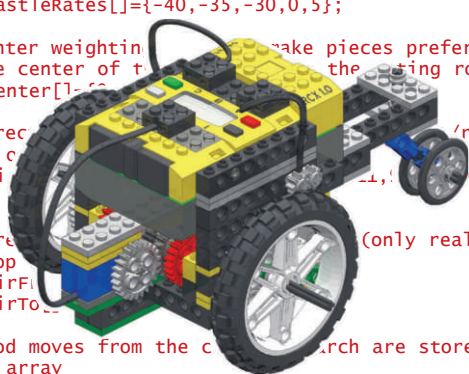

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LESSONS FROM THE LABORATORY

A
bi-monthly
column just for
kids!

— PART 6 —

FLL Competition: Team #8

by James Isom



Every September, millions of students dust the summer cobwebs from their brains and return to the classroom to once again start down the road of learning. As the memories of canoeing on the lake give way to lessons in history, science, and social studies, students find their days filled with new seasonal after-school activities, like soccer and

football. For others, it's all about the robots. For several thousand students around the world, September marks the announcement and subsequent launch of the FIRST LEGO League Robot Challenge season.

FIRST LEGO League (FLL) is an annual robot competition for 9-14 year old students. The competition season

runs roughly from September to January and consists of both regional and state competitions. Leading up to their regional competitions, teams work together designing, building, and programming their autonomous robots to complete a challenge that is based on real world problems.

Each year has a unique theme. Themes from years past include using robots in various capacities in the Arctic, solving problems in cities, and — most recently — challenges on the planet Mars. Teams are also encouraged to research and make a presentation to a panel of judges on how robotics might help solve a real problem facing the world today.

Meet team #8 from the San Rafael Community Center. Most members of the team have at least one season of FLL behind them. They come from a variety of schools in the area and are mostly sixth, seventh, and eighth graders.

Despite their best efforts, they have never made it to a state tournament, but have always had fun at their regional tournaments. They are hoping that their previous experience — mixed with a little hard work — will take them to the state tournament this year.

The theme for the 2004 season is

Team #8 — The Spectacles: From Left to Right, Top Row: Greg, Davis, Nick, Walker. Bottom Row: Aaron, Jake, Gabe, and Zach.



"No Limits" and highlights the needs of people who face physical challenges in their everyday environments. The team has decided to call themselves "The Spectacles" this year, paying homage to the LEGO glasses that are part of this season's challenge.

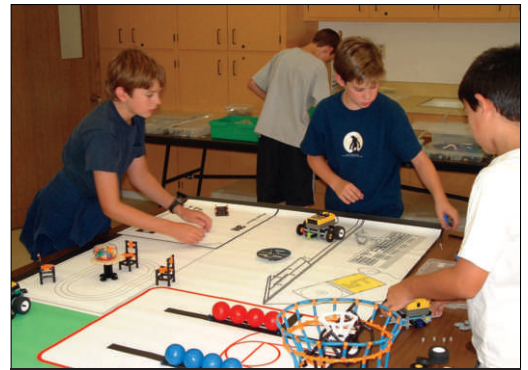
As I write this, the season has only just begun. The team has spent their first month formulating a strategy, assembling the challenge, and building a robot chassis.

The chassis design is a very important first step to each season. Several are usually built by individual team members and evaluated using a variety of criteria — the most important being the ability to drive in a straight line. This year, ideas from a couple of chassis designs were combined to make one "über chassis" that the team hopes will lead to success.

Now the design is decided upon and the team replicates it for use by each "challenge team" so they can work on different parts of the



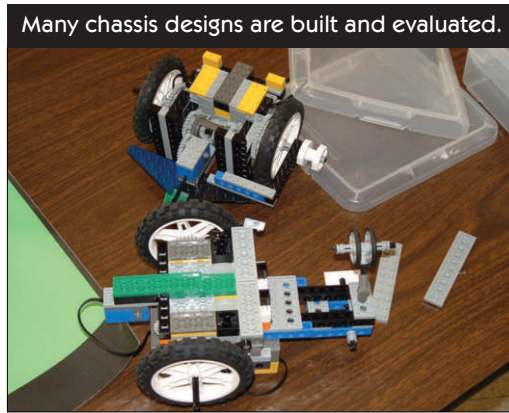
All the challenge elements must be built before the team can strategize.



Prior to the release of the rules, the team speculates on how it all might work.

challenge simultaneously. We will be discussing the "challenge teams" and their individual strategies and programs

in next month's article, but — for now — take a crack at building this year's chassis, which they have named "Spex."

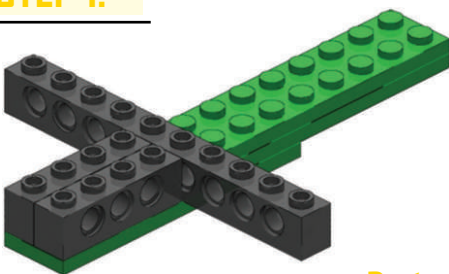


Many chassis designs are built and evaluated.

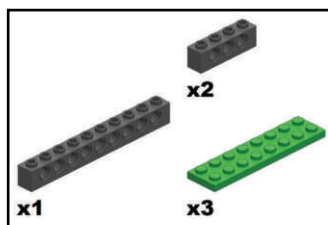


The completed challenge.

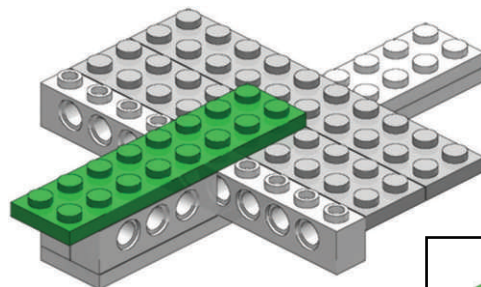
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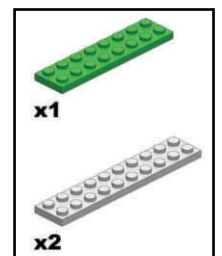
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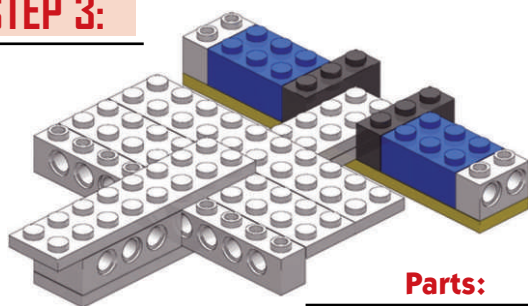
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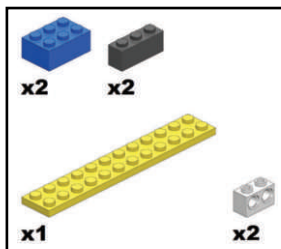
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STEP 3:



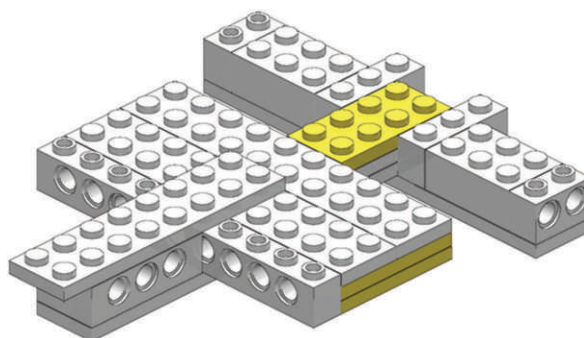
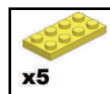
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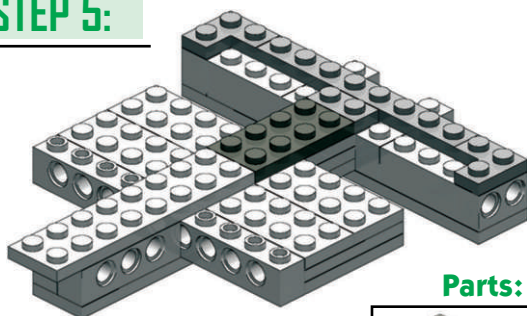
STEP 4:

Attach a double stack of 2 x 4 plates across each side of the 2 x 10 plates. Place a single 2 x 4 plate between the two 1 x 3 bricks.

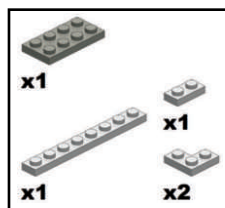
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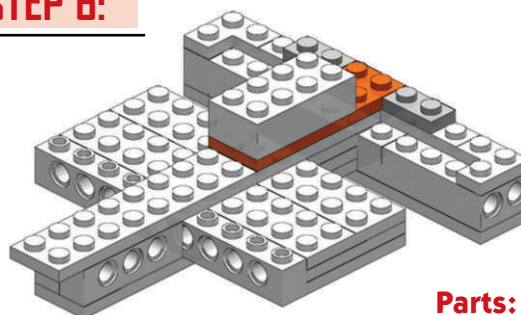
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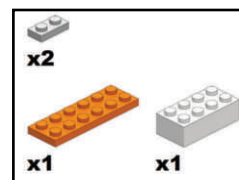
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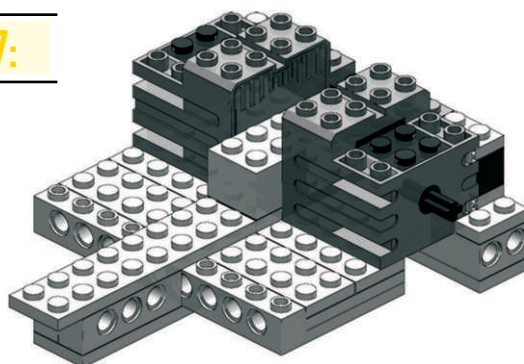
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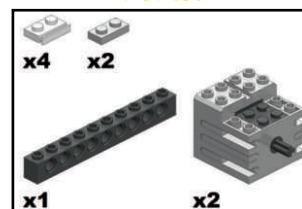
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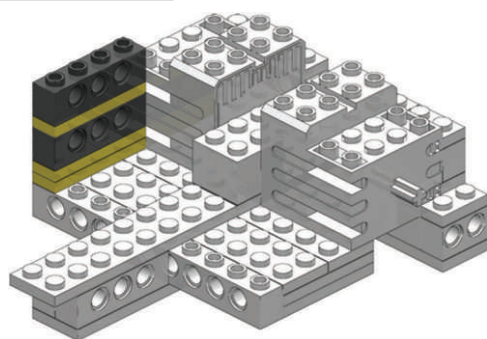
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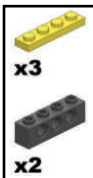
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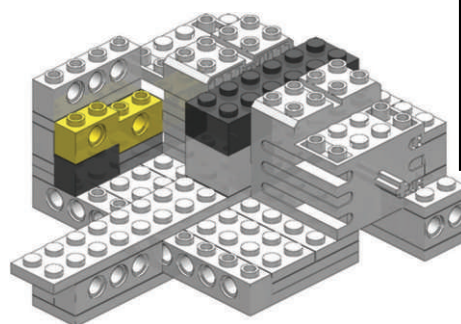
STEP 8:



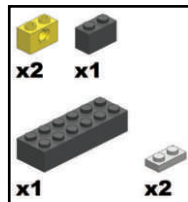
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STEP 9:

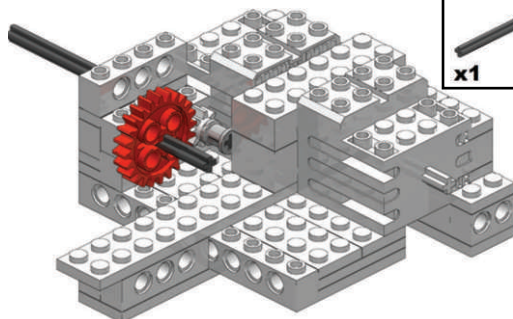


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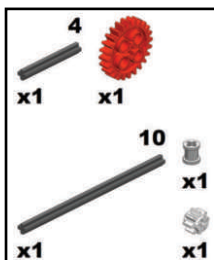


STEP 10:

The #4 axle with 24T gear goes in front. The #10 axle with the 8T gear and the bushing is inserted behind.

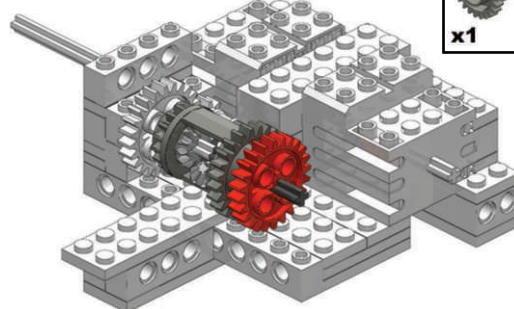


Parts:



STEP 11:

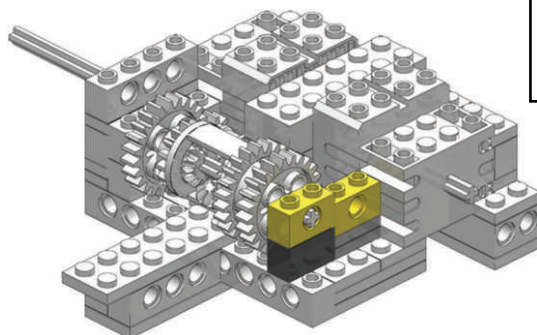
Build the differential with the axle and 12-tooth bevel gears and slide it over the axle from the previous step.



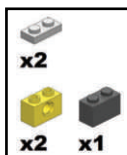
Parts:



STEP 12:

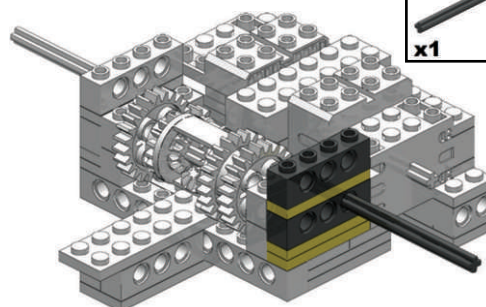


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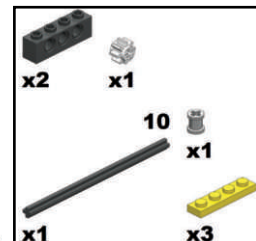


STEP 13:

Just like on the other side, insert the #10 axle, 8T gear, and bushing to finish off the drive mechanism.

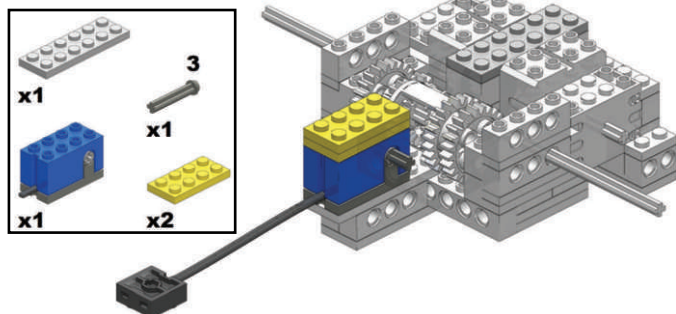


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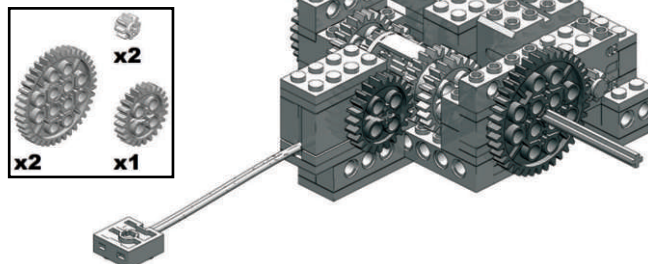
STEP 14:

Parts:



STEP 15:

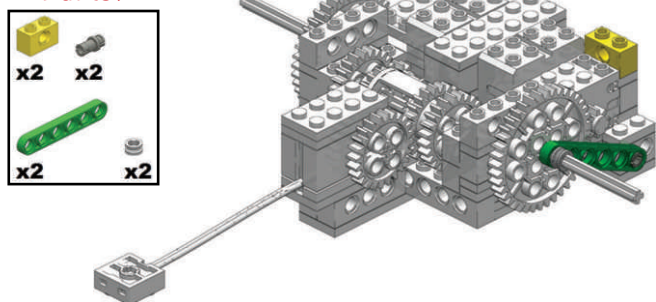
Parts:



STEP 16:

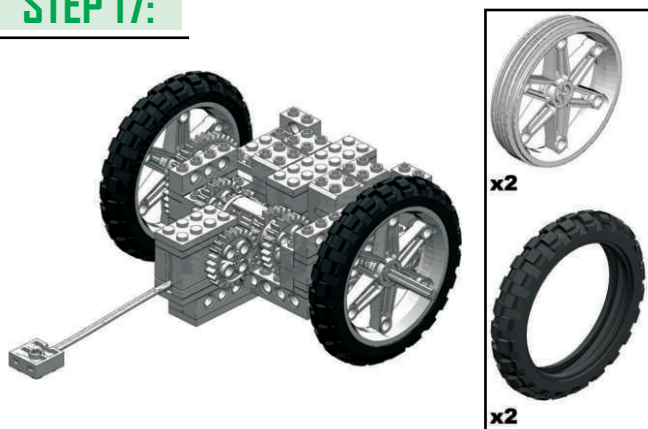
Place the two 3/4 pins in the hole closest to the 40-tooth gear. Slide the 1 x 6 lift arm over the axle and pin and secure it with a half bushing.

Parts:



STEP 17:

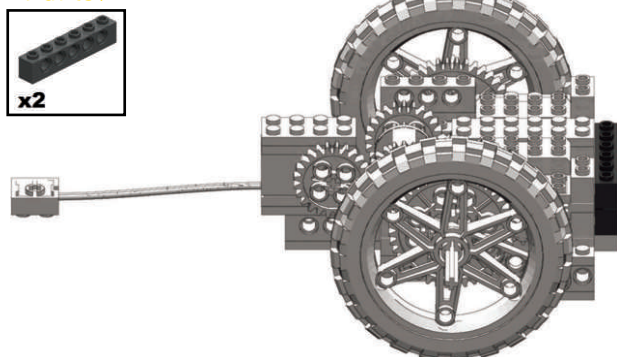
Parts:



STEP 18:

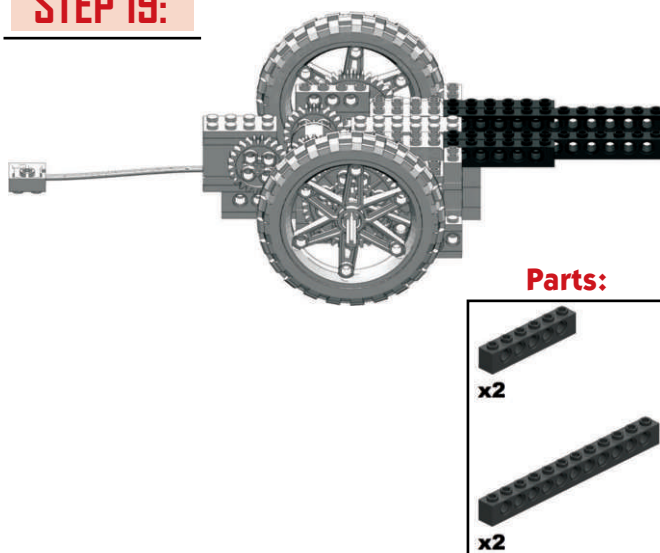
Stack on two 1 x 6 beams across the studs that are sticking out of the back.

Parts:

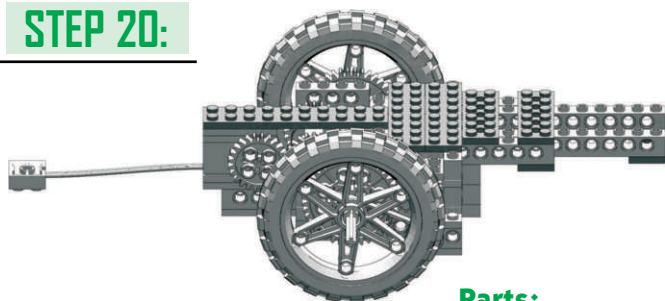


STEP 19:

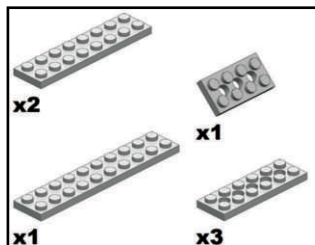
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STEP 20:



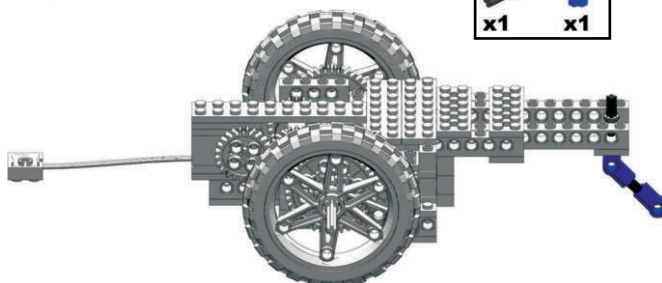
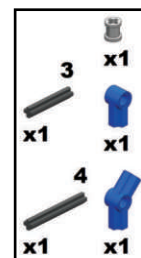
Parts:



STEP 21:

Insert the #4 axle through the 2 x 4 plate and place a bushing on top. Insert the #4 angle connector to the bottom of the #4 axle. Continue by placing the #3 axle followed by the #1 angle connector to complete the step.

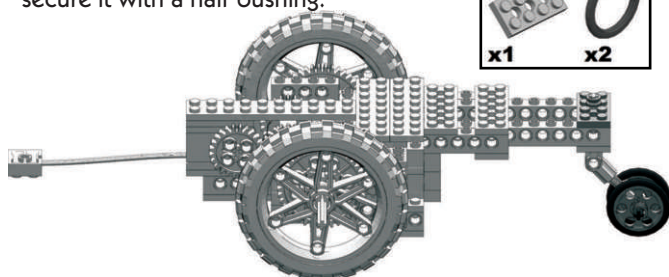
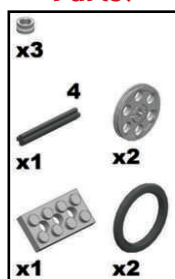
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STEP 22:

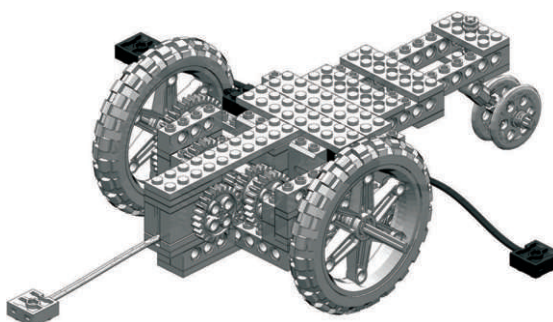
Insert the #4 axle into the #1 angle connector and secure it with pulley wheels and half bushings. Place a 2 x 4 plate with holes over the remaining axle that is holding the wheel mechanism to the tail and secure it with a half bushing.

Parts:

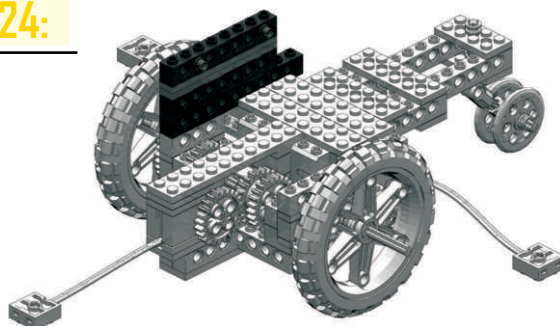


STEP 23:

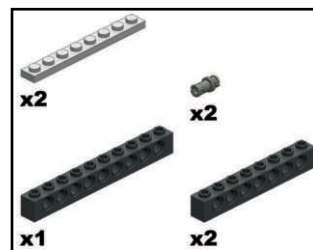
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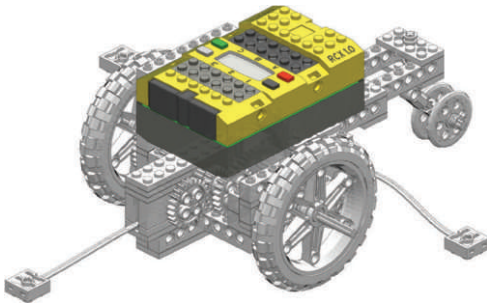
STEP 24:



Parts:



STEP 25:

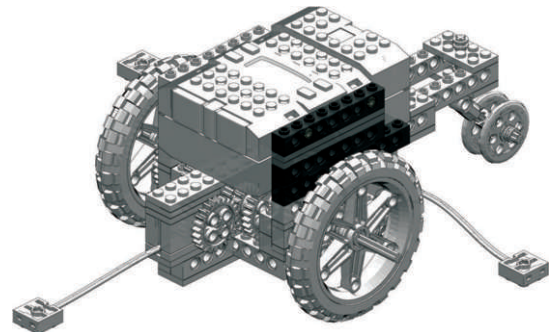
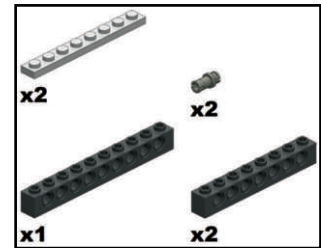


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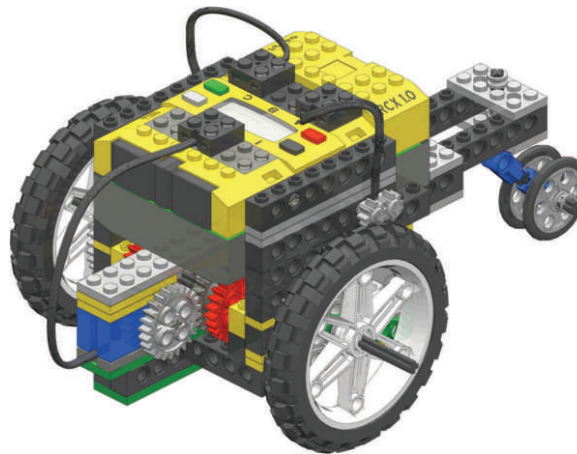
STEP 26:

Parts:



STEP 27:

Place the axle pins and 8T gears on the beams on both sides of the RCX. Congratulations — you're done!



Parts:



Next time, we'll take a look at the teams' individual strategies and programs, what worked, and what didn't. If you would like to know more about FIRST LEGO League, go to www.firstlegoleague.org. You can read more about "The Spectacles" at their website at <http://robotics.megagiant.com/fll/> **SV**

AUTHOR BIO

James Isom is a part-time robotics teacher and general all-around geek. He has taught robotics to children and teachers in the US and abroad. His website with other additional goodies (including the MLCAD file of this robot) can be found at www.the-roboticslab.com. He can be reached at james@megagiant.com





"Check out my driver's side.
Driver's side? I don't have a driver!"



Arctic Tortoise Robot Racing Team Military Goes Unmanned!

The Tale of the Arctic Tortoise?

The story begins, as many robotics tales do, with the US Government and DARPA. Prior to 2001, the Senate issued the Defense Authorization Bill for Unmanned Vehicles (UMVs). The bill included the following statement: "It shall be the goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that ... by 2015, one-third of the operational ground

combat vehicles of the Armed Forces are unmanned."

To facilitate R&D of military UMVs or Unmanned Ground Vehicles (UGVs), to be specific, DARPA funded the Grand Challenge — a race for experimental UGVs. Prize money (a million dollars or more per race) has been allocated by Congress through 2007. It will cost DARPA in the neighborhood of \$15 million to hold

these Grand Challenge events.

The first race had 15 qualifiers and no finishers, leaving a \$1 million cash prize unawarded. The second race — to

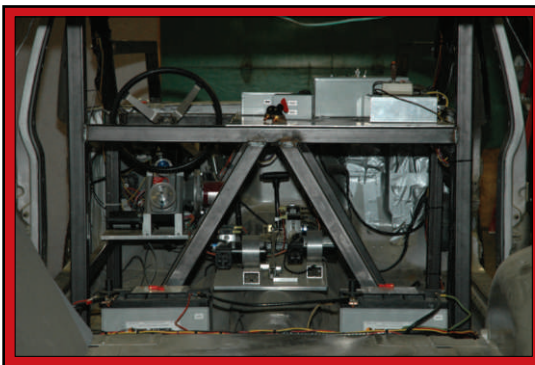
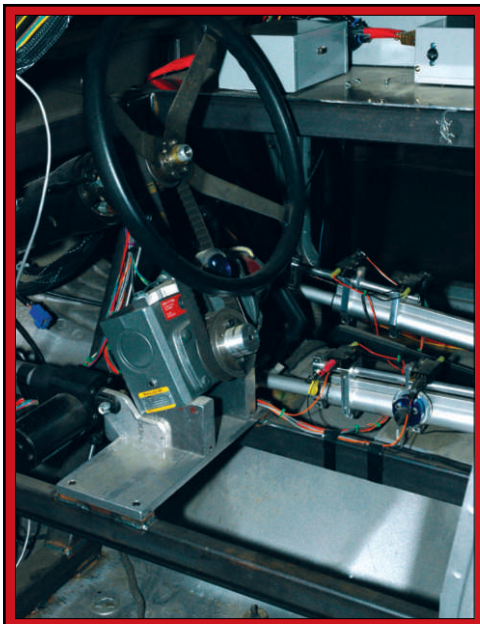
** Unless otherwise noted, all photos are courtesy of the University of Alaska Fairbanks Geophysical Institute Digital Design Center, photographed by Deborah Manning.**



Ten-four, good buddy, this is the Arctic Tortoise. I got my ears, I mean, sonars on.

be held in the spring of 2005 — doubles the prize money and the difficulty of the course, which is somewhere between California and Nevada in the deserts of the Southwest. The first team to complete the course in less than 10 hours wins two million smackeroos.

The lower part shows the steering motor and the brake and transmission actuators. The advantage of leaving the steering wheel is that the motor can be released with the tilt steering column adjustment and then turn the wheel by hand for maneuvering the vehicle.



I've never seen tortoise guts that looked like this before.

"Enter the Tortoise"

The Arctic Tortoise Robot, as you may have guessed, is one of the experimental autonomous ground vehicles now headed for race number two. The Arctic Tortoise is the creation of the Arctic Tortoise Robot Racing Team, a group of engineers from the Geophysical Institute of the University of Alaska at Fairbanks.

How Do You Build an Autonomously Racing Arctic Tortoise?

From the remains of a running (and perfectly good, mind you) '92 Jeep Cherokee, the Arctic Tortoise was formed. Equipped with anti-lock brakes and wheel encoders, a transmission controller, fuel injection, and other goodies, the Cherokee came with many features that could be repurposed to build the tortoise-bot from the cold, cold North.

Arctic Tortoise Robot team leader Rick Ruhkick and crew stripped the Jeep out — wiring, interior, the works. They installed a full roll cage, actuators for the brakes, a transmission transfer case, and steering. The existing cruise control vacuum actuator was converted into a throttle; the team modulates the vacuum valve using their own controllers. The team will be replacing the gas tank with a racing fuel cell to keep the gas and,

thus, the vehicle safe and secure; it also provides for longer range travel.

The Tortoise's brains are mounted just behind where the front seats used to be. The team kept the air conditioning unit to cool the computers, plumbing it back to the computer enclosure. The windshield area will be sealed off with aluminum; cameras and laser rangars mounted there will overlook the hood.

Ten sonar units surround the Arctic Tortoise. Vision and radar are used for long range sensing while the sonars are used for short range and for keeping the vehicle equidistant from the sides of tunnels and other narrow passageways. One laser ranger will be used to detect negative obstacles in the Tortoise's path.

A variable force sensor assists the Arctic Tortoise Robot in determining if an "unidentified sitting object" is something that can be surmounted, like a bush, or something they have to maneuver around, like a big rock. If they push against it and the sensor doesn't go off, they're good to go.

Computer Vision

Additional eyes for this Tortoise — which seems to have quite a few — will soon include a stereo or tri-camera system, which is currently under development by Konnect World, a company in the former Soviet Block region. Konnect World's robotic successes include an autonomous grapevine pruner. The robot uses computer vision in conjunction with an articulating arm and either a small saw blade or a dipper to do the pruning.

Konnect World is working on road following and algorithms in general, including obstacle recognition and avoidance. The Arctic Tortoise will be equipped with Konnect World's system, as well as long and short range vision systems. The Tortoise also uses Doppler radar to detect obstacles directly in its way.

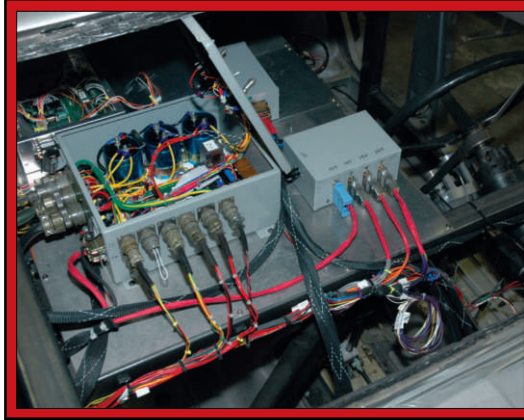
What's Joggin' the Tortoise Noggin'?

The brains behind the vision system include FPGAs or CPOPs and these are fed to two 1.8 GHz motherboards. One motherboard is almost completely dedicated to vision and the other is the primary computer brain, which makes decisions based on all the other sensing input.

Two custom FPGA boards will be used to process all vehicle feedback and sonar data at a rate of 20 Hz. This information is routed through two serial servers donated by LANtronics. All of the processing units will communicate over a 100 MB network. The communications protocol is UDP rather than TCP/IP, since the processing speed will be fast enough that a few missed packets won't really matter. Using UDP provides for less overhead traffic on the network.

The Tortoise Loves Torvalds

The Tortoise employs a Linux-



Talk about ingrown hairs! Is that Tortoise wired or what?!



"You got to actuate; use your actuators. Check my rear sonar here."

based OS. Rick Ruhkick noticed that other teams were using Windows-based systems in the previous race — a race that he studied closely; they were also running LabView.

Ruhkick's team chose Linux over Windows and LabView, in part, to escape the perils of "the blue screen of death," which most long-term Windows users have seen at one time or another.

Linux is desirable for the Tortoise because it is readily customized and stripped down, while still maintaining a full OS. Ruhkick's team customized its Linux installation to cut additional overhead while maintaining processing close enough to real time to serve

their needs.

What Will We Call Our "Baby"?

When the team began work on the autonomous vehicle, their goal was not to finish fast, but to finish at all. Why? DARPA had not yet established constraints on finishing the race within a set time period. Team Tortoise figured that, rather than knock themselves out with high speeds and not finish, they'd travel "slow and steady" and finish the race.

When a team member reminded

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GEERHEAD TO TEAM LEADER: WHAT'S YOUR 20, UH, YOUR STORY?

There's another path to racing at the DARPA Grand Challenge — the path a roboticist takes from being curious about robotics and building simple home bots to heading up a robot racing team. Here's the path Arctic Tortoise Robot Racing Team Leader Rick Ruhkick took to get within inches of racing this spring:

Rick has been involved in electronics since age 10. Though I won't reveal his age, he tells me that dates him back to the age of electronic vacuum tubes.

Rick has been interested in robotics for close to 20 years. For 12, he's been architecting and constructing small autonomous bots — "rugrats" as he calls

them — that run around the house and chase the cats. (Where were you when I was a kid, Rick?)

Ruhkick has been an engineering tech at the Geophysical Institute of the University of Alaska, Fairbanks for about five years. Rick was in the right place in his life, career, and joy of robotics and its surrounding technologies when along came word of the DARPA Grand Challenge.

Rick attended the Grand Challenge Competitor's Conference in February of 2003. Excited at the prospect, Rick felt ready to take the next step — the step into large scale robotics — for the DARPA Grand Challenge.

them of the Fable of the Tortoise and the Hare, the name Arctic Tortoise was born. Shortly after that, DARPA came out with a time limit for the race, but the name remains.

Autonomy

While observing the previous year's DARPA Grand Challenge, Ruhkick noted that some bots didn't exhibit obviously necessary autonomous behavior, like object recognition and

avoidance or the ability to back up.

Before the race, vehicles had to qualify on the Qualification, Inspection, and Demonstration (QID) course. DARPA positioned an old junk vehicle on top of one of the waypoints that are used to find the course. Waypoints provide a sort of GPS positioning landmark along the trail to make sure no one gets off course.

Certain bots that were not equipped with obstacle recognition and avoidance ended up backing into

the junk car and getting stuck. The bots didn't know that the junker was there or that they were stuck against it. In other instances, vehicles were not equipped to back up and change course. As Ruhkick put it, "even a cockroach gets into a corner and has to try something different."

The Arctic Tortoise has sufficient sensing to know what is going on all around it and sufficient mobility and autonomy to use sensed information to come up with and implement several options in traversing the course. In fact, the Arctic Tortoise can backtrack up to at least two waypoints, based on its record of where it has been and then start over from there, if needed.

The previously attempted path gets marked with a low probability of success and the bot takes the next best course of direction. The Tortoise can calculate several possible paths, which are all weighted with a high and low probability of success. If the first path doesn't work, it can go to the second best path, and so on.

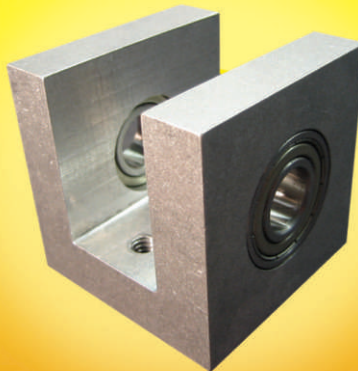
Tortoise Action for Teacher

The Arctic Robot Racing Team frequently invites groups of school children who are interested in robotics

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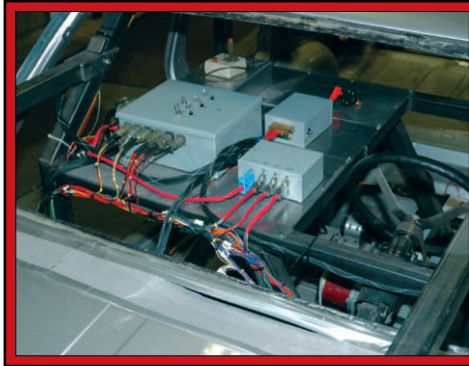
SPECIAL FOR SERVO READERS — VISIT WWW.TEAMDELTA.COM/SERVO

from areas surrounding Fairbanks to check out the Arctic Tortoise Robot. The team educates the kids about the nature and purpose of DARPA's Grand Challenge race and provides a tour of the Tortoise and its component systems, as well. The children are always very excited and full of questions.

A common question is, "Can I go for a ride?" After explaining to one young man that it could be very dangerous, as there is no guarantee that the Tortoise won't drive itself off a cliff, he asked, "Well, then, can my teacher go?" (I'm sure he was innocently thinking of the teacher's interest in robotics, aren't you?)

Future Races

Each consecutive race is expected to be more challenging as greater autonomy is sought. Suspected changes include fewer waypoints in order to create a demand for increased autonomy, more man-made obstacles to force everyone to acquire and use obstacle recognition and avoidance, and tank traps in order to require sufficient sensing on the vehicles.



There's no windshield where my windshield should be.

Give the Arctic Tortoise a Helping Foot

(It's Not a Flipper — That's Turtles, Not Tortoises.)

The Arctic Tortoise didn't make the first DARPA Grand Challenge due to funding constraints. The racing team is all-volunteer; the University and Geophysical Institute lend support — use of an electrical shop, machine shop, and a garage — but can offer no funding. Any needed dollars are raised through donations, contributions, and fund drives.

The team has received donations



The Arctic "T" shows off his horns and other plumage.

of gifts of equipment from folks like LANtronics. However, as of this writing, the team is still \$18,000.00 short of their goal to be able to attend the race this spring. If you would like to inquire about the Tortoise, the race, or the possibility of getting involved, you are invited to check out the following website dedicated to the Arctic Tortoise: www.arctictortoise.uaf.edu/Welcome.htm **SV**

RESOURCES

Arctic Tortoise's home on the web
www.arctictortoise.uaf.edu/Welcome.htm

How to participate in the DARPA Grand Challenge
www.darpa.mil/grandchallenge/team.html

A link for finding government surplus equipment, including vehicles and Jeeps
www.govliquidation.com/

LANtronics
www.lantronics.com/

A good source for autonomous robot kits
www.superdroidrobots.com/

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EVENTS CALENDAR

Send updates, new listings, corrections, complaints, and suggestions to: steve@ncc.com or FAX 972-404-0269

As you are reading this, it's December, but it's a warm, sunny day in the middle of October as I write it. The weather feels like anything but Christmas and New Year. I'll just have to use my imagination as I describe most of the robot events planned for December. The one exception is the Hawaii Underwater Robot Challenge, which will be held on December 6th in Oahu, HI. I expect there's no snow in the forecast there!

Two of the more strangely named events this month are for LEGO robots and they both occur on the same day in the same state: December 11 in OH. If you're in the Cleveland area, stop by the Great Lakes Science Center and check out the LEGO MY EGG-O Robotic Egg Hunt. This is a contest for students taking a robotics class at Case Western Reserve University. Student-built autonomous robots will work in teams of two, searching for colored eggs while protecting their eggs from other teams. Meanwhile, in Dayton, you can attend the Boonshoft Museum LEGO Mindstorms Robotics Competition, which is held at — you guessed it — the Boonshoft Museum. The Boonshoft event is a standard FIRST LEGO League event. On the 17th and 18th in Cherry Hill, NJ, the South Jersey Robotics Group will hold an event they're calling RoboPraxis; it will include some interesting events, like a robot collision avoidance contest, a RoboSapien race, and even a robot dance contest.

I've been writing this event column for just over a year now, but I've been maintaining the robot competition list for 10 years. During that time, I've seen a lot of robotics magazines come and go — mostly go — so I'm quite pleased to see that *SERVO* is still around and doing well. There are a lot of great folks contributing to this magazine and I'd like to wish them all a Merry Christmas and another year of interesting robotics adventures!

— R. Steven Rainwater

For last minute updates and changes, you can always find the most recent version of the complete Robot Competition FAQ at Robots.net: <http://robots.net/rcfaq.html>

December

- 6 Hawaii Underwater Robot Challenge**
University of Hawaii, Oahu, HI
Regional for the MATE ROV competition.
www.phys.hawaii.edu/~aapt/calendar/events/2003-04.html

- 11 Boonshoft Museum LEGO Mindstorms Robotics Competition**
Boonshoft Museum, Dayton, OH
This year's robotics competition will be a FIRST LEGO League event. The usual FIRST rules apply.
http://www.boonshoftmuseum.org/special_events.php3

- 11 LEGO MY EGG-O Robotic Egg Hunt**
Great Lakes Science Center, Cleveland, OH
A robot egg hunt for students of the Case Western Reserve University Autonomous LEGO Robotics class.
www.eecs.cwru.edu/courses/lego375/egghunt.html

- 17-18 RoboPraxis**
Cherry Hill, NJ
For this event, South Jersey Robotics Group has some very interesting events planned, including a robot dancing contest, a collision avoidance event, and a special contest just for RoboSapiens.
www.sjrobotics.org/

January 2005

- 24 Citrus Robotics Robot Combat**
Inverness, FL
Radio-controlled vehicles destroy each other in Florida.
www.citrusrobotics.com/

- 28-30 Techfest 2005**
IIT, Mumbai, India
A nationwide science and technology festival for Indian students. There are several robot contests, including Yantriki and Survivor.
www.techfest.org/

February 2005

- 4-6 Robotix**
IIT Khargpur, West Bengal, India
Organized for students of IIT Khargpur, this contest includes events for both autonomous robots and radio-controlled machines.
www.robotixiitkgp.com/

March 2005

6-10 APEC Micromouse Contest
Hilton Hotel, Austin, TX
This will be the 18th annual APEC micromouse event.
www.apec-conf.org/

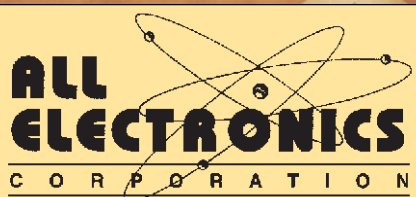
11-12 AMD Jerry Sanders Creative Design Contest
University of Illinois at Urbana-Champaign, IL
The design problem is new and different each year. Check the website for the latest news.
<http://dc.cen.uiuc.edu/>

19-20 Manitoba Robot Games
Manitoba Museum of Man and Nature, Winnipeg, Manitoba, Canada
A variety of events, including sumo, a robot tractor pull, and Atomic Hockey.
www.scmb.mb.ca/

April 2005

15 Carnegie-Mellon Mobot Races
Wean Hall, CMU, Pittsburgh, PA
The traditional Mobot slalom and MobaJoust events.
www.cs.cmu.edu/~mobot/

28-30 SAE Walking Machine Challenge
Montreal, Quebec, Canada
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www.sae.org/STUDENTS/walking.htm



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Most robotic applications involve some sort of movement. These movements might be anything from turning wheels to moving manipulator arms. Many times in robotics, these movements will be done as quickly as possible.

Other times, you may find it more desirable to have the movement happen over a period of time, as the robot is moving from one waypoint to another.

In that case, you may choose to use interpolation to make this happen. Interpolation allows you to command your mechanism to go from point A to point B in many smaller steps instead of one large one. This month's column will cover linear and curve-based interpolation and will talk about how to implement this on a PIC microcontroller.

Let's start with linear interpolation. If you wanted to interpolate between two points in even steps along a line, then you would first need to figure out how many intermediate steps you would like. Let's say that, for this

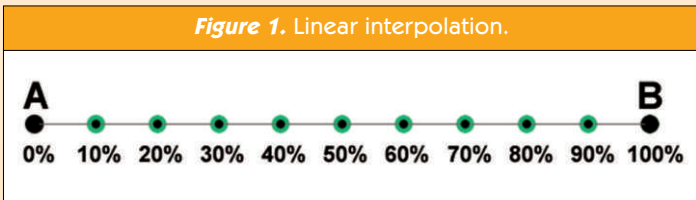
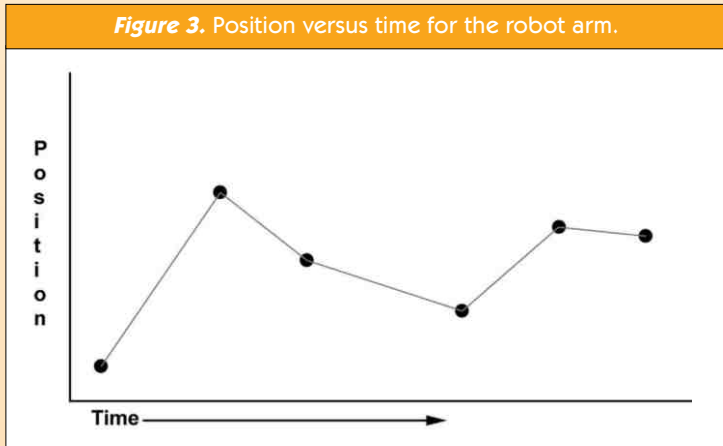


Figure 2. The values of the interpolated points.

Point A	22
1/10	26.8
2/10	31.6
3/10	36.4
4/10	41.2
5/10	46
6/10	50.8
7/10	55.6
8/10	60.4
9/10	65.2
Point B	70



example, you would like 10 steps. This makes the math easy for us. Take a look at Figure 1 to see an example of what linear interpolation looks like with 10 steps between point A and point B.

Let's say that point A has a value of 22 and point B has a value of 70. If you wanted to find the second interpolated point, then you would do the following: First, you would find the distance between point A and point B. In this case, it is $70-22=48$.

Next, you would find the fractional value that you would be multiplying by. In this case, you want the second interpolated point out of 10 so you would be multiplying by $2/10$ or $.2$.

Now, multiply your fractional value ($.2$) by your range (48) to get the position along the range. The result at this step is 9.6. One last thing is to add back in the value of point A to shift your answer's value to where it really should be. The final interpolated value in this case is 31.6. Figure 2 tabulates all of the interpolated points between the starting and ending points.

In the example, 10 points were used because 10 is a simple number for us to work with. Computers have an easier time working with numbers that are multiples of two, so a better number of interpolated points might be eight or 16 if you are doing interpolation in your robot's program.

Let's look at how this is useful in robotics. Let's say that you have built a robotic arm that you want to move around. Let's also suppose that you built it with a really powerful motor that – when commanded to move from one point to another – would move at full speed between the points and then try to stop immediately. That might be great for an industrial robot, but you built this arm mainly to look good and impress your friends, so you would like it to move more smoothly. In that case, you would

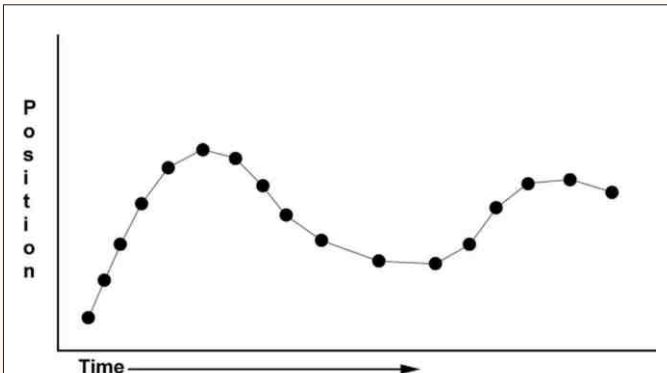


Figure 4. Smoother linear interpolation.

use interpolation to create movements that look like what is shown in Figure 3.

This movement is pretty good. It succeeds in slowing down the arm so that it doesn't move so quickly. Maybe your goal is to impress your friends with the quality of movement of your robot arm.

If that is the case, then you still may not be happy with how your robot arm is moving. To put it rather bluntly, the movement would still look robotic. There are a couple of things that you could do to smooth things out. The first is to simply add more points to interpolate between. Figure 4 gives an example of this.

The problem with what is shown in Figure 4 is that you will need to either store or transmit all of these points in order to achieve the smooth motion that you desire. It might take up all of your available ROM to store a short movement or it could really bog down your serial line to have to send so much data. An alternative to linear interpolation is to interpolate along a curve.

Many textbooks and web pages do a terrible job of explaining this relatively easy concept. What will be shown here is how to interpolate along a Bézier spline. A Bézier spline is a curve that is defined by three or more points, called control points. The first and last control points define

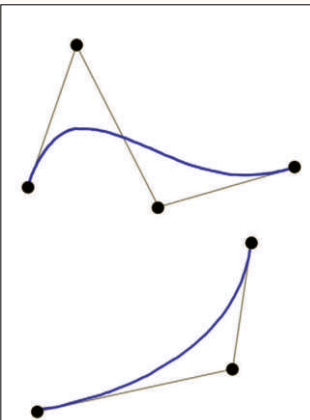


Figure 5. Bézier splines with four (top) and three (bottom) control points.

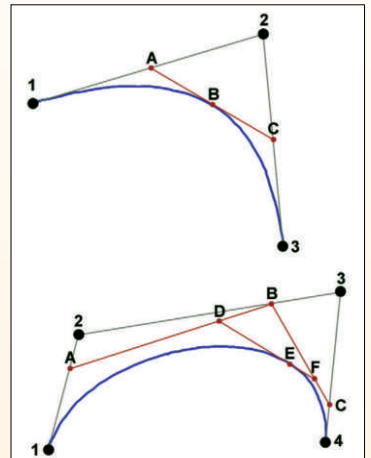


Figure 6. Calculating a Bézier spline.

where the curve will start and stop. Other control points do not touch the curve, but help define its shape. Figure 5 shows some examples of Bézier splines.

Looking at Figure 5, you can see that the control points which are not at the edges influence the shape of the curve. You can think of them as being like magnets that pull at the curve. One other thing to notice is that — at the

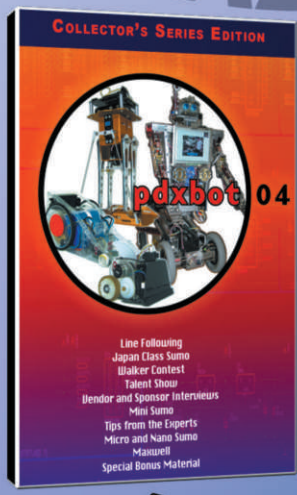
TECH TIDBIT

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You can now use this tool to carefully pry your chips out of their sockets without disturbing other electronic parts that are near it and without fear of bending your chip's pins.



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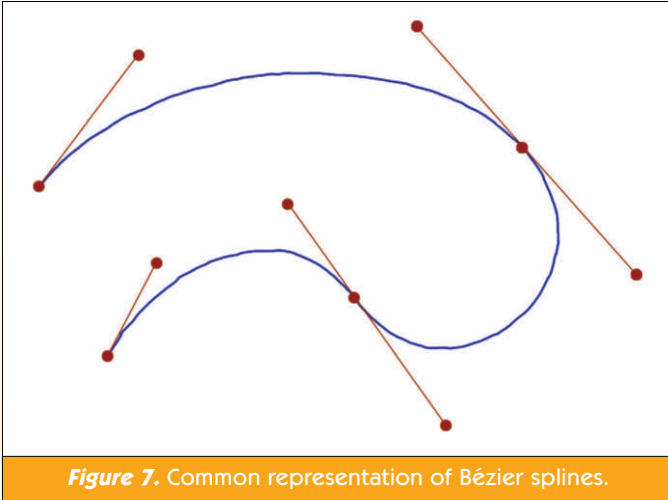


Figure 7. Common representation of Bézier splines.

ends of the curves — the curve is tangent to the line segment formed by the control points on the end and next to the end.

Let's look at how to calculate the shape of a Bézier

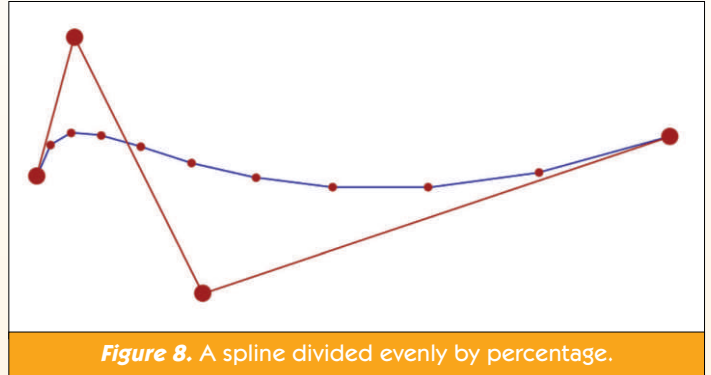


Figure 8. A spline divided evenly by percentage.

spline. Figure 6 gives a visually intuitive example of how to calculate a point along a spline.

First, let's look at the example at the top of Figure 6. This is a spline that has three control points. In the previous examples, the X-axis represented time and the Y-axis represented position. This is the case with these examples as well, but it is not as easy to just pick a time and work backward to arrive at a position.

For now, let's look just at how to calculate points on the spline. When doing this, you are finding points at a certain percentage along the spline instead of at a specific X-axis location.

The top example in Figure 6 shows how to arrive at point B, which is 50% along the spline. The control points are numbered 1, 2, and 3. The first thing that you would do is find —through linear interpolation— point A, which is 50% between points 1 and 2. Then find point C, which is 50% between points 2 and 3. The next thing that is done is to find the point that is 50% between points A and C. This is the point that is 50% along the spline.

The bottom example in Figure 6 shows how to find a point that is 75% along the length of the spline. It follows the same process as the three control point spline, which was to linearly interpolate a certain percentage between consecutive control points and then use those resulting points for the next round of linear interpolation, repeating the

Listing 1. C code to do linear and spline interpolation.

```
int16 linearInterpolate(int16 pointA, int16 pointB, int8 distance)
{ /* does linear interpolation between points A and B in 64 steps. Distance
  represents how many 64ths along the spline the interpolated point should be.
  Points A and B should be no more than 1024 units away from each other */
  int16 result;
  if(pointA > pointB)
  {
    result = pointA - pointB;
    result *= distance;
    result /= 64;
    result += pointB;
  }
  else
  {
    result = pointB - pointA;
    result *= distance;
    result /= 64;
    result += pointA;
  }
  return result;
}

int16 splineInterpolate(int16 pointA, int16 pointB, int16 pointC, int16 pointD, int8
distance)
{ // does Bezier spline interpolation along the curve
  //defined by points A, B, C, & D in 64 steps
  int16 point1, point2, point3, point4;
  //calculate the first three intermediate points
  point1 = linearInterpolate(pointA, pointB, distance);
  point2 = linearInterpolate(pointB, pointC, distance);
  point3 = linearInterpolate(pointC, pointD, distance);
  // calculate the next two intermediate steps
  point4 = linearInterpolate(point1, point2, distance);
  point1 = linearInterpolate(point2, point3, distance); //reuse point 1 to save RAM
  // calculate the final point
  point2 = linearInterpolate(point4, point1, distance); // saving RAM again
  return point2;
}
```

process until there is only one point left. This point will be the one that is 75% along the spline.

As they have been described here, splines may not seem so useful. That is true. If they are used individually, then you cannot describe a very complex series of movements with them. Splines are almost never used individually.

More often, you will find many splines being used where their endpoints are connected. This allows you to create a motion path that is as complex as you can dream up. Take a look at Figure 7 to see an example of how they are often represented in computer programs, such as graphic programs or animation packages.

If you look carefully at these splines, you can see that they are a series of three four-control point Bézier splines that are connected at their endpoints. Another thing that you will notice is that — where the splines connect — the control points next to the ends and the endpoints of the splines are collinear. This ensures that the splines are tangent to each other at their endpoints and that they flow smoothly into one another.

It was mentioned earlier that Bézier splines couldn't be directly used for time versus position plotting because you are actually plotting a percentage along the spline to get a point along it. Figure 8 shows a situation where you would end up with irregularly spaced points along the X-axis if you

divided the spline into even percentages. If you used each point as an evenly spaced point in time, then your actuator would not move correctly.

An additional step is needed in order to find a specific point on the X-axis of a spline. A commonly used method is to find the points by percentage and then use those points to linearly interpolate to get points which are evenly distributed through time.

As you can see from this month's column, using splines can be a bit computationally intensive, but they will allow you to create infinitely smooth curves that you can use as motion paths. In Listing 1, you will find code meant to be compiled using the CCS C compiler for the PIC that will allow you to do linear or spline interpolation. **SV**

RESOURCES

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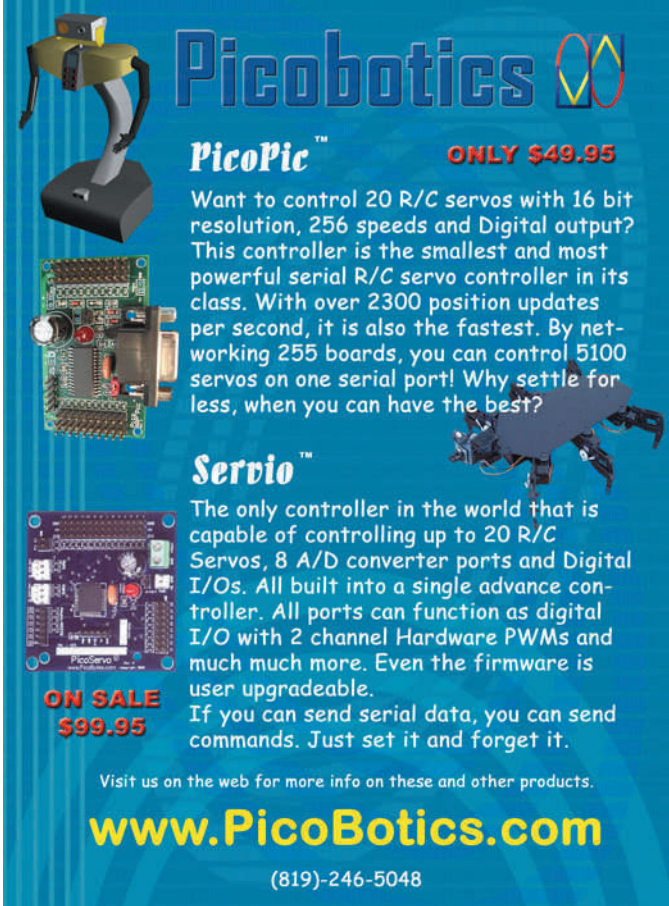
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Melanie III

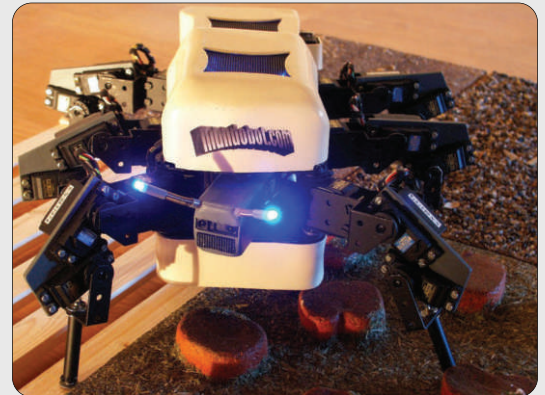
All of the robots this month are from the lab of Alejandro Alonso-Puig, Spain

Melanie III is a hexapod robot with three degrees of freedom in each leg, that can transport a payload twice its own weight. It has several interesting capabilities, like direct programming, the generation of movements

by displacement of waves combined with inverse kinematics, and the capacity to walk on rough terrain, like rocky or slatted surfaces.

The robot works with an external computer through a wireless link. It is a research robot, with 30 sensors and 18 motors, for testing different ways of walking (gaits) and avoiding obstacles.

<http://mundobot.com/>



Brutus

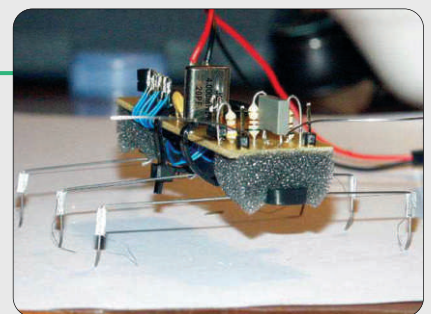
Brutus is a robot designed for rough terrain environments. Although it could go to a specified place on its own while avoiding obstacles along the way, it can also be remotely controlled from an external computer. This robot was built to perform mobile robotics research on rough terrain environments. Obstacles are detected by a steerable ultrasonic sensor on the front, with back-up sensing embedded in the front bumper.



Stalex

Stalex is a hexapod based on the structure of Stiquito (www.stiquito.com). The locomotion system uses Muscle Wires, made of Nitinol. Its mission consists of moving as far as possible avoiding the obstacles that are in its way.

Muscle Wire is a shape memory alloy, and contracts 3-5% along its length when resistively warmed by the application of an electrical current. It returns to its normal state when it has cooled off. The contraction is fast (0.5 s), but the relaxation is slower, and depends on the thickness of the wire (0.7 s for a wire of 37 μM and 14.5 s for 375 μM .) The legs are made of steel wire and therefore they are relatively elastic. The robot has contact sensors on the front (antennas) that allow it to detect obstacles.



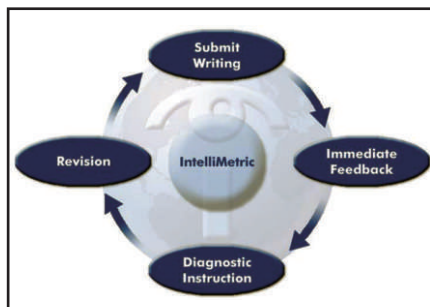


Guest Hosted by the *SERVO* staff

Where in the world is David Calkins? Many fear that he has been kidnapped due to his involvement with the Robo-Equality Party. Others imagine that he had an unfortunate mishap while engaging in selfless experiments to create cyborgs. Nevertheless, he seems to have disappeared ... As a result, this month's "Robytes" was written by *SERVO* staffers.

If you happen to see a man — probably clad in some form of historical costume — who seems to have a dazed look in his eye, but sports a cyborg arm capable of lifting a crate of Guinness Stout without effort, please help him find his way home to his robots. They miss him!

Aibo Ate My Homework



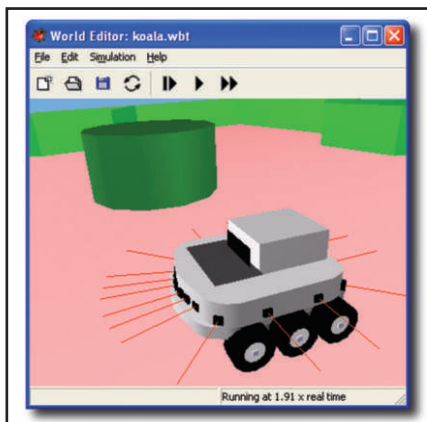
The analysis cycle.

Teachers not only have to spend their days trying to corral unruly kids, but they are also obligated to spend their evenings and weekends grading papers. Until now. Vantage Learning (www.vantagelearning.com) has developed IntelliMetric, the software that will have teachers tossing their red pens in the trash can with all the contraband gum and paper airplanes.

Software that identifies plagiarized papers is nothing new (although most students still think it's on par with cryogenics), but this is something more. IntelliMetric has been enhanced by the addition of E-Fence™, which uses an advanced blend of artificial intelligence and digitized human experience to score and assess open-ended essay questions.

Research shows that IntelliMetric scores match those given by human teachers 99% to 100% of the time. This is accomplished through E-Fence, a brilliant software system that identifies responses submitted in essays that are not legitimate. It utilizes several natural language processes, machine learning, and statistical tools to restrict responses and evaluate essays in comparison with the goal to be learned. Now, teachers might just be able to find a way to convince students that hacking a GameBoy is just as interesting as playing one.

A Robotics Dry Lab



Webot in action!

Wouldn't you love to test drive a robot before you invest any sweat and solder in it? Cyberbotics understands the dilemma of producing versus product and offers a solution: Webots 4 robotics simulation software.

Webots offers a rapid prototyping environment for modeling, programming, and simulating robots. Whether your ideal bot has wheels, legs, or wings, Webots has a model for you — complete with sensors and actuators. You get to program your virtual bot in C, C++, Java, or third party software.

Once your virtual bot is programmed, you can even transfer the controllers to real mobile robots — such as Aibo, LEGO Mindstorms, Khepera,

Koala, or Hemisson. This software provides a prototyping area, evolution of behaviors, modeling of biological systems, and even robot soccer capabilities. In addition, Cyberbotics provides the ultimate in rosin core-free robot fun: an online robot competition. Once you model and program your virtual bot, you can enter it in a contest, pitting its programming against that of others. See the Cyberbotics website — www.cyberbotics.com — to find out about their upcoming online robot challenges and let the soldering burns on your fingers heal.

Ahoy, MATE!



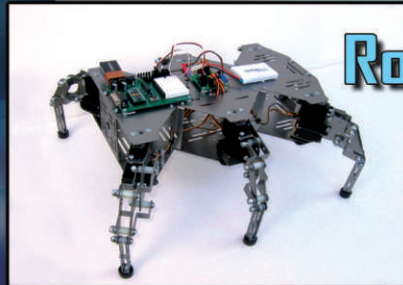
Stinky gets a bath.

Members of the Carl Hayden High School Falcon Robotics team recently scored a first place win in the third annual Marine Advanced Technology Education (MATE) National ROV championships. Their PVC-based underwater robot — "Stinky" — was a computer-controlled machine with an onboard color camera that allowed the pilot to remotely drive the sub around.

With Stinky beneath the waves, the team had to accomplish various tasks — like pumping fluid from a "toxic" can into a sample retrieval container and searching a "reef" for objects to collect with a grappler. The tasks of underwater robots are on the rise, as we showcased in last month's issue of *SERVO* — perhaps an underwater project or two should be on your to-do list for 2005. No harm in trying to ride *this* wave! **SV**

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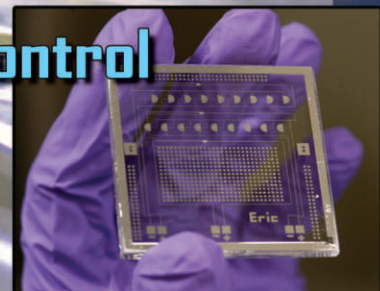
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APPETIZER

ENGINEERING IN THE GARAGE

by Alex Sulkowski — Team Xela

Four months, a reciprocating saw, a drill, a garage, Home Depot, plus \$1,200.00 equals one exoskeleton. I wrote down this list of my limitations when I read the rules for the Tetsujin competition in my copy of *SERVO Magazine*, thought about what I had to work with, and decided to take the challenge. It had been 10 years since I had done any real building and my day job in credit card consulting (figuring out what rates and credit lines to give you) does not give me access to a machine shop.

So why enter? The contest objective was simple: lift a heavy Olympic barbell as high and as fast as possible with the lightest exoskeleton. The manner in which to succeed, however, was not obvious and the rules left a lot of room for different approaches to the challenge. I added a self-imposed requirement: I would actually walk in the exoskeleton. I thought it was missing the point to have an exoskeleton that the operator did not actually walk in.

I think that *SERVO* intentionally made the rules very broad so that both the contestants and their exoskeleton solutions would be diverse. As the *SERVO* web page stated, it was up to each contestant to decide whether or not to focus on picking up the heaviest weight or to rely on a fast and light suit picking up a lighter weight. Based on the variety of entries and the response of the crowd at the competition, I think *SERVO* was not disappointed.

My Design

The basic scoring formula was: weight lifted x height of the lift / (weight of the exoskeleton and the

operator)/# of seconds to complete the lift.

Since I did not have the resources to build an exoskeleton that could lift weights near the maximum allowed (1,500 lbs), I focused on creating a lighter suit with a faster lift (that's a strong emphasis on *fast*) that used the strengths of the operator and the machine while minimizing their weaknesses. The low weight of the suit, along with the articulated joints in the ankle, knee, and waist allowed me to walk using my ability to perform highly coordinated motion (although a high center of gravity was an issue that came back to haunt me later).

When the weight was lifted, the machine's strengths took over; pneumatic pistons in the ankles straight-

ened the legs and very large pneumatic pistons located next to the operator's arms picked the weight up — very fast. The true advantage of this design was that I could build it with my limited set of tools and with parts from the local Home Depot.

This was critical for me because it was the only store to which I had easy access and where I could see (and touch) the material before I bought it. Since I did not know how to compute the strength of the material I needed, I could often be found in the Home Depot aisles, jumping on different widths of angle iron that was elevated off the floor on two by fours. This provided a very scientific way of determining which materials and widths would be strong enough.

Though this was not his highest scoring lift, Alex pushed his exosuit to the limit with a 450 lb attempt on the last day of competition.



The Event

The actual lifting was very exciting — both for the competitors and the audience. In most cases, the competitors were really testing their exoskeletons on the spot, as prior testing at home was limited by the time needed to complete our projects and the lack of a proper safety system for lifting such heavy weights.

My exoskeleton (Team Xela) won. With it, I could not pick up the most weight, but — relative to the other competitors — it was very light (130 lbs) and — even more importantly — it was fast. Although I lifted 450 lbs, my best score came from a 250 lb, 3 foot lift, which was timed at 0.4 seconds. I had to use my body to steady the exoskeleton at the end of the lift because of the momentum generated by the weight moving that fast.

In fact, my exoskeleton was truly that — a complement to my body. All this from a suit that cost \$1,300.00 and looked like it was built from an Erector set on steroids.

The truly interesting part of the competition was the variety of solutions to the competition. Mechanicus was a 1,000 lb marvel of engineering that looked like it came straight out of the movie set for *Aliens*. (There was a constant crowd of people having their pictures taken next to it.) It had hydraulic pistons in every joint that would eventually allow its operator to walk and was built to lift 3,000 lbs.

Team Technotrousers had an elegant design that moved like a piece of

gym equipment and was powered by electric motors. The Widgets (a high school team) built a very light-weight pneumatic suit with each point of articulation powered separately. Team Raptor had a surprisingly light-weight suit, given that it could pick up as much weight as the Olympic barbell could handle by virtue of hydraulics.

Since a picture is worth a thousand words (and this article is only about that long), my brief description of these suits does not do them justice; I suggest looking at pictures of these creations that were built in a mere four months (see pages 34 and 35). I have only highlighted the variety of solutions that were presented, since it was the variety that impressed me the most.

The Path Forward

I mentioned earlier that the exoskeleton was not yet very stable when I walked in it. When I walked up in front of the crowd of several hundred spectators to receive the award for winning, I stepped on an extension

cord used for lighting. Just this little bit of an incline caused me to lose my balance in the suit and fall to the ground. Although the suit is relatively light, I could not get up and had to be picked up.

While it would have been hard to plan a more embarrassing entrance, I am not bothered by my fall at all. We had four months to build exoskeletons and five competitors succeeded, all taking very different approaches to solve the problem: pneumatic, hydraulic, and electric power applied to very different structural frames. You have to start somewhere and I started in my garage.

Based on what *SERVO* editor Dan Danknick has said, the competition will be more challenging next year — possibly with walking and stacking requirements. I can't wait to see the creative solutions people come up with. I am sure that many of the solutions from this year will be used and improved upon. I already have plans for my next exoskeleton to defend my title. **SV**

Author Bio

Alex Sulkowski is a principal at the financial services consulting firm Argus Information and Advisory Services where he specializes in credit card profitability. On the weekend, he goes into the garage and transforms into an inventor where he combines the electrical, mechanical, and biomedical engineering he learned at Yale and Johns Hopkins Universities. He can be reached at ASulkowski@ArgusInformation.com



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